ADDIS ABABA INSTITUTE OF TECHNOLOGY

CENTER FOR ETHIO-MINES DEVELOPMENT

DEPARTMENT OF MINERAL ENGINEERING

GRADUATE PROGRAMS

ENHANCING THE CALORIC VALUE OF COAL DEPOSIT USING FLOTATION METHOD IN LALO DISTRICT, SOUTH-WESTERN ETHIOPIA

BY

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A project that was turned in to the Addis Ababa Institute of Technology's Center for Ethio-Mines Development to partially meet the criteria for a master's degree in mineral engineering

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Addis Ababa, Ethiopia
February 2025

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

CENTER FOR ETHIO-MINES DEVELOPMENT

Approval sheet

This project paper entitled "ENHANCING THE CALORIC VALUE OF COAL DEPOSIT USING FLOTATION METHOD IN LALO DISTRICT, SOUTH-WESTERN ETHIOPIA," prepared by **Megersa Biratu** and submitted as partial completion of the requirements for the Master of Engineering project work at the Center for Ethio-Mines Development, Addis Ababa University, in the department of mineral engineering, is suggested to be accepted and approved for the final oral defense.

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Declaration

This project, "Enhancing the caloric value of coal deposit using flotation method in Lalo district, Southwestern Ethiopia," is my own work, and I hereby confirm that it has not been submitted or presented for credit towards a degree at any other university. I also adequately acknowledge all of the sources of the materials used in this project.

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ACKNOWLEDGEMENT

Most importantly, I want to thank God Almighty for his favors during my project effort. I owe a debt of gratitude to the professors, physicians, and lecturers who taught and trained me in this mineral engineering program, as well as to the Ethiopian mine scholarship program that Addis Ababa University coordinated with the Addis Ababa Institute of Technology faculty for enabling me to study here.

I want to express my sincere gratitude to my primary advisor, Dr. Melese Alemayehu, and my co-adviser, Dr. Bekele Ayele, for their encouragement, direction, tenacious advice, and insightful counsel. I also want to sincerely thank my parents, who were a huge help in discussing my issues, as well as all of my friends, coworkers, and classmates for their support, encouragement, and aid with this effort.

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ABSTRACT

Lalo coal reserves are mainly lignite and contain high ash coals therefore, it is important to enhance these low-quality coals. Coal applications are impacted by high ash content; hence improvements are required to lower the ash content of coal in our nation. Tests were carried out to investigate and determine the effect of parameters like particle size and collector dosage on reducing ash content from coal. The particle size observed to have the most significant role in coal ash, followed by the collector dosage. The optimum particle size and collector dosage values were -100+75µm and 7ml respectively. The results from the flotation study on a laboratory scale at optimized conditions revealed an increase in carbon content from 26.16% to 39.07%, decrease ash content and sulfur content from 25.75% to 20.09% and 0.47% to 0.21% respectively.

Using a high ash content coal sample from the Lalo district coalfield, flotation is used in this study to improve the quality of coal samples to remove the ash and impurities.

Keyword: Coal, ash, flotation, particle size, collector, recovery, caloric value

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Coal is an extremely dominant source of energy in the world, because it is abundant and rather cheap. Being a fossil fuel, its consumption rate is very high in electricity generation and even more so in countries that have large coal reserves. According to the International Energy Agency (Tian et al., 2022), coal contributes about 36% of electricity production worldwide and therefore forms a large component of the energy balance in many parts of the world. To lessen energy problems and boost economic growth, coal provides more affordable and reliable electricity.

Apart from that, the combustion of coal wastage is a source of serious environmental consequence; coal in general contributes to air pollution and greenhouse gas emissions. The reliance on coal as the primary energy source raises pressing debates over transitioning to cleaner alternatives while addressing socio-economic impacts for communities reliant on coal mining and production.

However, one of the biggest issues with the usage of coal has to do with its ash content, which poses major environmental and health risks. The combustion of coal results in the release of nearly 130 million tons of coal ash annually in the United States, through which numerous toxic substances like arsenic, cadmium and mercury are released into the atmosphere (Ku et al., 2021). This byproduct is often stored in unlined landfills or ponds, which results in leaching into groundwater and neighboring ecosystems. It is revealed from these studies that leaching of toxic elements from coal ash may vary widely depending on its chemical composition and prevailing environmental conditions, thus making its management and mitigation complex (Popov et al., 2021).

Coal ash poses specific environmental threats but also poses a threat by way of long-term health effects across the populations that dwell in any proximity to disposal sites. Contaminated water sources may result in serious health effects, such as cancer and neurological damage, especially in children and the elderly (Shaheen et al., 2014). Incidents like the Dan River in Jordan spill have shown how coal ash mismanagement can have disastrous consequences, releasing millions of gallons of toxic waste into local waterways and setting off widespread ecological damage and public health alarms (Nayak et al., 2022). To solve these problems, different researchers have tried to develop different beneficiation techniques to reduce coal impurities and enhance the energy density (Mishra et al., 2015). Therefore, it is essential to reduce ash from coal prior to its use in many applications (Longjun et al. 2012). By eliminating mineral matter, coal beneficiation raises the fixed carbon content and raises the coal's calorific value. It includes limiting gas emissions and particle pollutants, decreasing slagging, fouling characteristics, and combustion behavior (Behera et al., 2018). Coal beneficiation prior to its combustion is important not only for environmental protection but also for improving the coal quality. In general, the run-of-mine (ROM) coal requires the removal of ash forming inorganic matter either by dry or wet processing methods. The physical characteristics of coal and mineral materials, such as density, size, shape, luster, electrical conductivity, magnetic susceptibilities, and frictional coefficient, are the basis for the dry beneficiation techniques. Based on the difference in these properties, different types of coal cleaning technologies are based on physical and chemical cleaning. Chemical cleaning is restricted to lab scale due to its cost and low efficiency. The Physical cleaning method consists of dry and wet cleaning processes, which are applicable to differently sized fractions and have been developed to benefit from ROM coal. Because wet beneficiation processes provide high-quality products with high recovery, they are widely used worldwide. Wet beneficiation techniques that are applicable to various coal size fractions, including jig, spiral, froth flotation, and heavy media separation, are used all over the world (Dwari and Rao et al., 2007). Among all these processes, flotation method is most suitable for coal washing. At the beginning run of mine (ROM) coal should be washed to reduce ash content, volatile matter, moisture content and sulfur. The current study aims on the separation of coal from ash content by using flotation method to evaluate the coal quality in Lalo district, southwestern Ethiopia.

This flotation effect is studied based on varying parameters, i.e., particle size and collector dosage.

1.2. Statement of the Problem

High ash content of coal is a big problem, which adversely affects the efficiency of combustion and overall energy utilization**.** According to Alam et al., (2021), the constituent of high ash coal has low calorific value and is responsible for slag and clinker formation**.** Ethiopia is working towards maximizing its industrial development through coal processing, integrated planning, and resource utilization efficiency. Despite these efforts, industrial development is unavailable due to a lack of technological advancement and integrated planning and proper utilization of its resources to improve low grade coal. According to Ethiopian mining sector (2016), Capacity challenges exist within the government at both the federal and regional levels. In the private sector, a lack of mining vocational skills and educational centers is seen as a threat to job creation. And linkages between the mining sector and the Ethiopian economy are weak due to the small size of the mining sector. According to Genetu & Kebede (2024), inconsistencies in the grade and quality of domestic coal make it problematic for industries. The technique of froth flotation today is an innovative method to remove silicate minerals from iron ores, separating coal from ash-forming minerals, separating potassium chloride from sodium chloride, and separating sulfide minerals from silica gangue. For coals and fine-grained ores that are not appropriate for gravity concentration, it is particularly beneficial (Biswal & Rath, 2025). It works well with fine coals (less than 1 mm), such as slack coal, mine dust, washing rejects, slurries, etc. So, to enhance Jimma Zone Lalo district's coal, flotation-based separation has to be carried out for our economic development and its utilization.

1.3. Objective

1.3.1. General objective

The main goal of this program is increasing caloric value of the coal deposit at Lalo District using froth flotation.

1.3.2. Specific objectives

- Characrerize the coal deposit from Lalo district
- To optimize froth flotation parameters

1.4. Scope

Enhancing the caloric value of coal through processes of flotation is broad, including quality enhancement, economic benefit, and suitability to other materials.

1.5. Significance of the study

The value of research on enhancing the caloric value of coal via flotation procedures is its ability to enhance the quality of coal, raise recovery levels, reduce the cost of operation, and lessen environmental problems associated with coal burning.

1.6. Location and accessibility of study area

Dedo district is one of the 21 districts of the Jimma Zone which is located 375 km from Addis Ababa and 20 km from Jimma zone. Geographically, the deposit is situated 7° 27'-7°30' N and 36° 45'-36° 50' E latitude and longitude, respectively. The area consists of Trap volcanic and sedimentary rocks. A small village named Lalo is located approximately 16.15 kilometers from Dedo woreda (Fig.1).

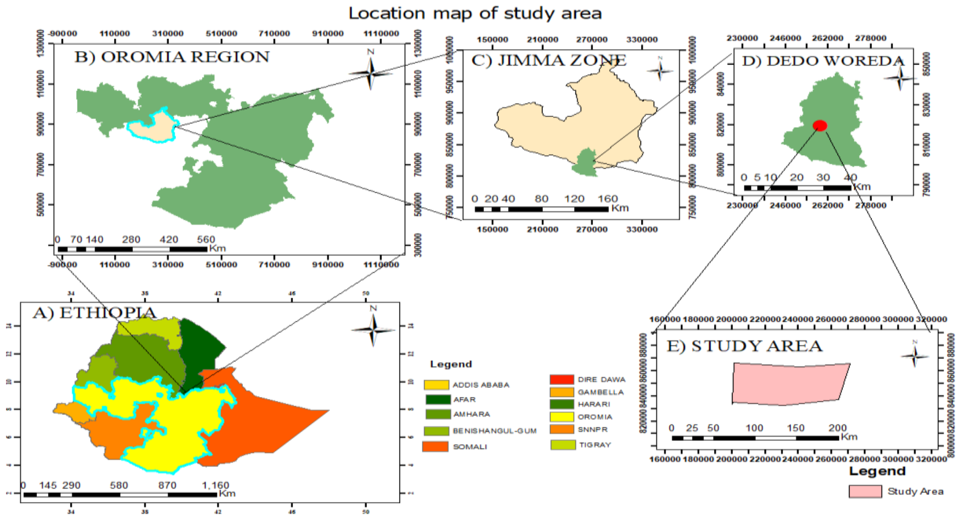

Figure 1: The study area's location map

1.6.1. Physiography

Lalo district, an important geological feature in Ethiopia, is rich in fossil fuel resources. It is characterized by its graben structure, substantial coal reserves, and generally different depositional environments. Graben formation lies within the NNW-SSE trending graben structure that has influenced the deposition of sediments and the accumulation of fossil fuels. Sedimentary formations are characterized by different sedimentary facies, having lower and upper sedimentary formations. Coal reserves are sapropelic in nature, showing features like brownish to black color, with massive and prismatic fractures. The coal seams reach a maximum thickness of 2 m. The sapropelic coal seams are characterized by a brownish to black, with massive and prismatic fractures. The environment of deposition becomes the prime controlling factor regarding the distribution, thickness, and quality variation of coal deposits in this area. The sediments of the basin were deposited in several environments, including lacustrine and fluviatile settings. This variability contributes to the rich organic content of the coal deposits.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Coalification

Coalification means a geological process that transforms organic material, mainly plant matter, into coal through heat, pressure, and time. This process occurs in stages, including peat formation, lignite development, bituminous coal generation, and, lastly, anthracite formation, which reflects increasing carbon content and energy density. Coalification is a biological process that occurs in a biological stage that occurs in peats and then transforms into coal through the action of moderate temperature and high pressure in a geochemical stage. The degree of coalification increases progressively and can be defined by the measured carbon/hydrogen ratio and the residual contents of oxygen, sulfur, and nitrogen (Straka & Sýkorová et al., 2018).

The coalification process refers to the building up of various processes, including physical, biological, and chemical, such as dehydration, bituminization, debituminization, graphitization, and peatification. Vegetative material from coalification goes from peat, lignite, sub-bituminous coal, bituminous coal, anthracite coal, and graphite. The period of exposure and temperature play primary roles throughout coalification, while pressure decelerates chemical reaction during coalification but prefers sandstone.

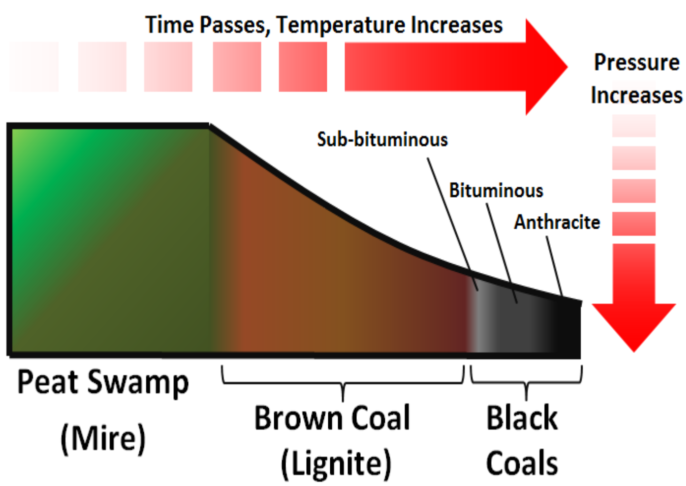

Figure 2: General trends that produce coal with the different types of coal that exist

2.2. Ethiopian Coal Deposits

Ethiopia has significant coal deposits in the Inter-Trappean geological setting of the southwestern plateau. These sediments bearing coal, ranging in age from Eocene to Miocene, were deposited in fluvio-lacustrine and paludal settings in grabens and half-grabens formed by fault system (W. Ahmed et al., 2008). The coal deposits are classified into Inter-Trappean and Pre-Trap volcanic geological settings. These coal deposits have been investigated and assessed since the early 1940s, and the Geological Survey of Ethiopia and Addis Ababa University have collaborated in discovering and evaluating coal resources (Genetu & Kebedeet al., 2024).

Ethiopian coals are typically lignite to high volatile bituminous, characterized as humic, sapropelic, and mixed coals. The coal seams vary in thickness, reaching up to 4 meters, with the thickest and most persistent seams found in sandstone coal–shale facies. Significant deposits are in the Delbi-Moye, Chilga, Yayu, Lalo-Sapo, Nejo, Wuchale, and Mush Valley Basins. The total known coal deposits in Ethiopia are inferred to be 600 million tons, with 70% of this amount found in the Geba Basin (Genetu & Kebede et al, 2024).

The Delbi-Moye Basin is particularly attractive for investment due to the good quality of its coal, which is suitable for thermal combustion, the considerable land area, and the potential for open-pit mining. The Yayu coal deposit has been the target for detailed exploration and mining since 2007, with an estimated reserve of about 250 million tons (Haftu Medhin & Konka, 2024).

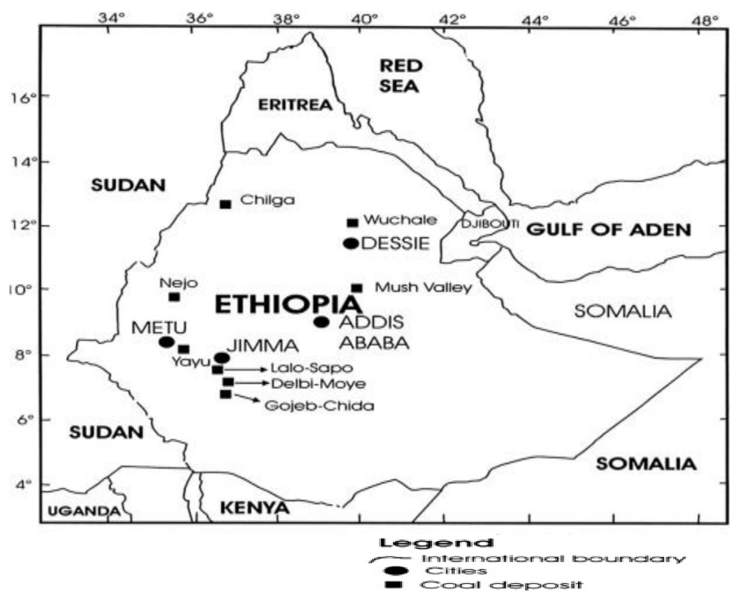

Figure 3: Ethiopian maps of coal occurrences and distribution (W. Ahmed et al., 2008)

2.3. Coal Rank Classification

Its site in the ranking of peat-to-anthracite transformation gives coal a grade that fixes its largely determined physical and chemical features. It involves systematic alterations of physical and chemical parameters in material when experiencing rising levels of heat, pressure, and duration of stay, what comes to be termed coalification (Jovanovski et al., 2023).

Lignite: The lowest quality coal, which has a carbon content of 65-70%, the lowest energy density at 17-18 MJ/kg, and the highest moisture content. Lignite is typically brownish in color and has a low energy density. It is used primarily in steam-generating power plants (Alpern & Lemos De Sousa, 2002).

Sub-bituminous: It is a grey-black or dark brown coal, an intermediate between lignite and bituminous coal. Its carbon content is between 70-76% and energy density of 18-23 MJ/kg. Sub-bituminous coal is one of the most used types and represents 30% of coal resources (Mohamad et al., 2013).

Bituminous: Bituminous coal has the second-highest rank of coal with a carbon content of 76-86% and a fairly high energy density of 23-33 MJ/kg (Jovanovski et al., 2023). It is the most prevalent kind of coal and is ideal for producing steel, coke and cement as well as electricity.

Anthracite: With a carbon concentration of 86–97%, anthracite is the highest rank of coal. Often referred to as "hard coal," this coal is black, shiny, and brittle. It has the highest energy density of all coal types, at 32-33 MJ/kg (Jovanovski et al., 2023).

2.4. Reagents Used in Flotation

Flotation is a separation technique in the physical sense, which works on particle surface properties' differences; it is basically determined by their hydrophobicity or hydrophilicity. The basic principle of flotation lays in some particles sticking to the air bubbles and then going up towards the liquid surface, whereas other particles sink. Chemical reagents are used in the process of coal flotation to boost the process. They include collectors such as diesel oil and kerosene used quite often to carry out the process of coal slurry flotation (Kadagala et al., 2021a). Frothers such as alcohols play an important role in stabilizing the froth phase. Others such as modifiers like dodecyl tetraoxyethelene ether ($C_{12}E_4$) are used in improving adsorption on coal surfaces (H. A. M. Ahmed & Drzymala et al., 2012). The yield and efficiency of coal flotation are greatly influenced by reagent selection and dosage, and studies have shown that mixed systems of reagents can improve the performance of flotation, especially for oxidized coals (Jia et al., 2002). The use of these reagents is critical in modifying the coal surface for improving its hydrophobicity and enabling attachment to air bubbles during flotation (Polat et al., 2003). This process heavily relies on the use of surfactants, usually chemical agents, which alter some surface properties of the particles. The surfactants can enhance hydrophobicity in the particles of coal so that they are more attached to air bubbles. The created froth, after binding with the hydrophobic particles, then skimmed off, thereby separating valuable coals from the impurities and unwanted ash (Mondal et al., 2021). Flotation efficiency is also affected by different particle properties, such as size, shape, and density. Smaller particles have a higher surface area-to-volume ratio, which may increase their interaction with bubbles but also lead to increased slime coating, thus decreasing flotation efficiency. In addition, particle density is also highly important; lighter particles float while heavier particles settle. The understanding of such properties facilitates optimization in flotation processes, for example, adjustments in operating parameters like pH levels, reagent, and dosages to achieve better separation outcomes. Thus, the interaction among surfactants and particle characteristics is essential in attaining maximum recovery rates and improving the general efficiency of coal flotation processes.

2.5. Methods for Separation of Coal from Ash Content

Coal ash is one of the residues of coal combustion, presents both environmental challenges and opportunities for resource recovery. A number of methods have been developed to separate unburned carbon and other valuable components from coal ash; each has its advantages and disadvantages.

2.5.1. Wet Extraction Methods

It includes crushing the fly ash to reduce the particle size, mixing into slurry, and making full use of gravity separation to isolate the coal particles from lighter impurities. Wet extraction technique is easy and cheap, conserving the fly ash resource efficiently to mitigate environmental pollution. With this method, despite its advantages, impurities in coal slurry are often present; further purification steps must be taken. Besides, this process does not need high-purity coal, which may be a disadvantage in those applications where the demand for high-quality fuel exists (Wierzchowski et al., 2020).

2.5.2. Froth Flotation

This process involves the addition of chemicals that adsorb selectively onto carbon particles that are not burned, thus floating while heavier ash descends. Froth flotation is recovering high percentages of unburned carbon. The process is chemically sensitive to the composition of the ash and can demand extensive optimization for different types of ash (Wierzchowski et al., 2020).

2.5.3. Dense Media Separation (DMS)

Heavy media is an effective method for separating material density differences with a suspension containing high-density media such as ferrosilicon to establish a difference between lighter and denser particles. Advantages that can be derived from DMS are high efficiency at small material density differences, good cleaning, and suitability for a wide range of minerals. It can handle a wide range of particle sizes and is very efficient for low-grade ores, improving overall recovery rates while reducing processing costs. On the other hand, DMS also has its negative side: it is extremely expensive to operate since medium preparation and recycling is required; it has environmental issues in terms of waste disposal; and it is ineffective for very fine or coarse particle sizes. Besides, the process needs constant monitoring for optimum separation efficiency, and the process is not applicable for minerals of almost the same densities (Pillay et al., 2022).

2.5.4. Spiral

Spiral concentrators are used to process heavy mineral sand deposits, including monazite, zircon, ilmenite and rutile deposits. More recently, spiral concentrators have been widely used to recover fine coal as well as gold, iron ore and other minerals. The disadvantages of spirals include relatively high specific gravity cut-points, relatively low unit throughput, the need for multi-stage processing, and limited acceptable feed size range. The specific gravity and particle size of the minerals being processed, the water flow rate and pressure, as well as the shape and size of the spiral channel, have an impact on the effectiveness of spiral concentrators (Ramsaywok et al., 2010).

3.5.5. Dry Separation Methods

Dry separation techniques include several processes such as electrostatic separation, triboelectric separation etc.

2.5.5.1. Electrostatic Separation

This technique utilizes the differences between unburned carbon and ash particles in electrical conductivity. Particles are being charged, and then separation on the basis of different response of the charged particles is affected to an electric field. Electrostatic separation is applied very well for fine particles and a high degree of purity achieved on recovered carbon. Humidity and distribution of particle size could have an effect on efficiency and might result in inconsistent performances of this method (Wierzchowski et al., 2023).

2.5.5.2. Triboelectric Separation

This separation mechanism is similar to electrostatic separation, except that this relies on the triboelectric effect in which the particles are electrically charged by friction prior to separation. This has the ability to work well with fine particles and to be installed within existing processing lines. Many times, effective separation requires sensitive control of operational parameters, hence complicating the process (Yang et al., 2020).

2.5.5.3. Size-Based Separation

Size-based separation is a further separated into size fractions by sieving or air classification techniques. In many cases, the concentration of valuable elements increases with decreasing particle size. This is a very simple technique that may effectively enrich critical elements, such as rare earth metals, in a specific size fraction. Although this process is quite adequate for certain applications, size-based separation alone may not be sufficient to fully recover all valuable components within the ash matrix (Karan et al., 2024).

CHAPTER THREE

3. METHODOLOGY

3.1. Materials and Reagents

The tools used for this project are displayed in Figure 4: laboratory jaw crusher (Fig. 4a), laboratory centrifugal mill (Fig. 4b), weighing balance (Fig. 4c), oven (Fig. 4d), laboratory wedag flotation cell (Fig. 4e), muffle furnace (Fig. 4f), sieve shaker with different mesh sizes (Fig. 4g), crucible (Fig. 4h), and adiabatic bomb calorimeter. Among the reagents utilized were n-octanol as a frother and kerosene as a collector.The collected samples were subjected to crushing, grinding, sieving, and flotation to minimize the effects of oxidation and moisture adsorption. Oxidation alters coal surface properties, decreasing its floatability and affecting adsorption behavior. Contrary to this, samples are usually handled under inert conditions (e.g., in nitrogen), stored in vacuum desiccators or air proof bags suitably labeled to reduce exposure to air and moisture (Somasundaran et al., 1991). Drying of the coal at controlled temperatures (e.g., 105°C) before analysis removes inherent moisture to avoid interference either in adsorption studies or in flotation operations (Yang et al., 2024). These preparation procedures ensure that the subsequent analysis is accurate and reliable by ruling out externalities like oxidation and moisture. Experimental studies were carried out employing a flotation machine with 2-liter cells. The impacts of collector dosages and sample size on the separation of coal from ash content, recovery, and grade are investigated while frother dosage and impeller speed are kept at constant values. In flotation studies, n-octanol, widely used in coal, was used as a frother and kerosene as a collector.

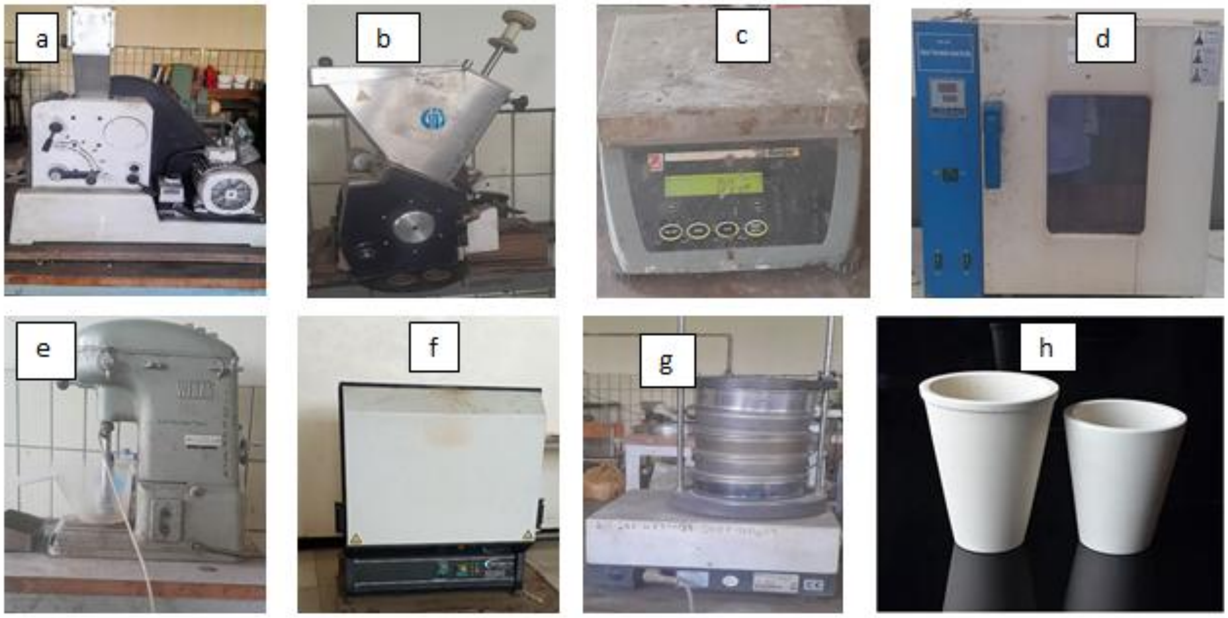

Figure 4: Laboratory materials used

a) Jaw crusher b) centrifugal mill c) weighing balance d) oven e) wedag flotation cell f) muffle furnace g) sieve shaker with different mesh sizes h) crucible

3.2. Sample Collection Parameters

3.2.1. Sample Handling and Shifting Mechanisms

Coal sample preparation is a critical process to ascertain the nature and quality of a coal batch, including a series of operations for reducing the weight and size of the sample without changing its chemical and physical properties. The key operations are reduction, division, mixing, sieving, and drying. Documenting the sampling date, sample type, sample origin (mine, location), and sampling protocol activities is crucial for maintaining the integrity of the study. Additionally, it is important to record any environmental conditions at the time of sampling, as these factors can influence the results and overall conclusions drawn from the data. Analysis should be conducted with a robust methodology to ensure that the findings are both reliable and valid. By implementing strict protocols and regularly reviewing procedures, researchers can minimize potential biases and strengthen the overall quality of the study. Common mechanical sampling systems contain crushers to crush the coal sample and facilitate downstream processing of the sample material. Sieving separates non-acceptable samples for re-crushing to the desired size. It employs the use of a cascade of sieves of various meshes, with vibrating screen machines largely substituting for manual labor.

3.2.2. Sample Preparation Techniques

The comminution was performed primarily through the Denver Jaw Crusher (Fig. 5a). The product of coal obtained from the jaw crusher was then subjected to further size reduction by the laboratory hammer mill (Fig. 5b). After the size reduction of coal samples, sieving was carried out through a sieve shaker by following American Society Testing and Material and weighing (Fig. 5c). Sieve analysis of powdered (size less than 0.5mm) coal sample was carried out to evaluate the particle size division. The coal samples of particle sizes (-100+75 µm, -150+100 µm and -250+150 µm) were selected for flotation (Fig. 5d), collecting froth concentrate and drying (Fig.5e), and ash analysis (Fig. 5f).

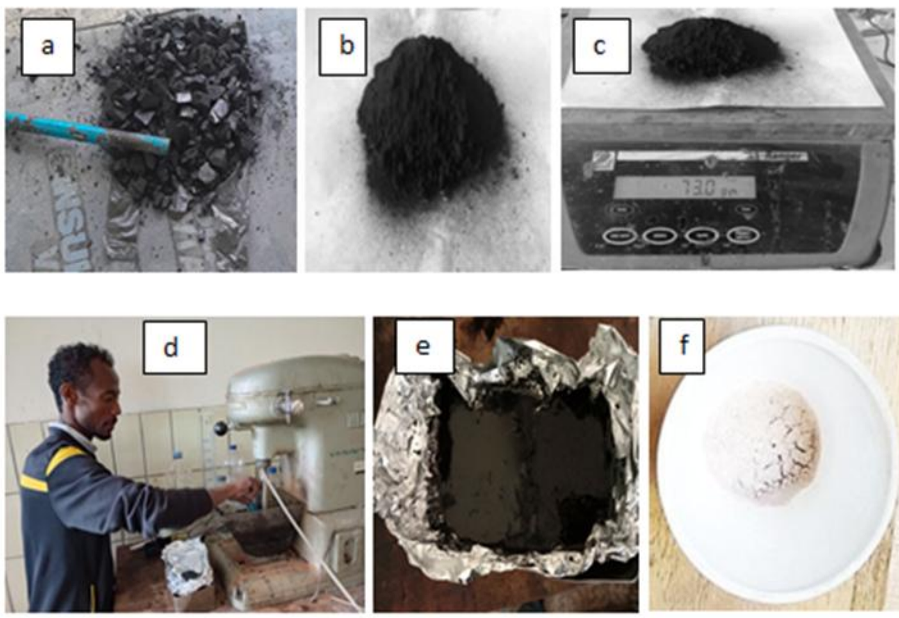

Figure 5: Sample preparation techniques

a) Comminution b) Further size reduction by the Hammer Mill c) Sieving was carried out through a sieve shaker and weighing d) Sizes were selected for flotation e) Collecting froth concentrate f) Ash analysis

3.3. Flotation procedures

At first, the flotation cell tank, with a capacity of approximately 2 liters, was cleaned with tap water. The amount of 100 g of coal sample with a specific particle size (-250+150µm, -150+100µm, -100+75µm) was added to the tank. Then, 2 litter of tap water was added to the water tank. The flotation cell was switched on, and the speed of the impeller was set at a fixed rpm of 1500 for all tests. For conditioning, 3 minutes was provided before adding reagents. After complete agitation of 3 minutes, kerosene oil was added (7 ml, 6 ml & 5 ml) as a collector to enhance the coal sample's hydrophobic properties according to American Standard and Testing Material (ASTM) standards. The slurry was further agitated for 3 minutes, and then frother was added (4 ml n-octanol) to stabilize the air bubbles and stirred for 3 minutes. The air valve remained closed during agitation. The air intake valve was then opened slowly until the froth formed. The machine was stopped, and the froth was collected with the help of a scraper in a tray as a concentrate and tailings were collected separately. After two hours of drying at 105 ^{0}C in an oven, the flotation concentrate was weighed and its ash content was examined. The effect of particle size and collector dosage was studied for optimum impurities reduction and recovery. The ash content recovery was determined using the following equation (Saydut et al., 2008).

$$\textbf{Recovery (\%)} = \frac{\mathbf{c\,C}}{\mathbf{f\,F}} \times \mathbf{100}$$

Where c- is ash content in concentrate, C - concentrate weight (g), f - ash content in the feed, and F – feed weight (g). Also, to calculate Grade for each flotation process, using the formula as follows.

$$\textbf{Grade} = \frac{\boldsymbol{Weight\ of\ pure\ Coal\ in\ concentrate}}{\boldsymbol{Weight\ of\ Concentrate}} \times \mathbf{100}$$

The analyzed parameters in the laboratory experiments are shown Table 1.

Table 1: Laboratory experiment Parameters

Particle size (µm)	Feed (g)	Collector dosage (ml)	Frother (ml)	Impeller speed (rpm)
-250+150μm	100	7, 6 and 5	4	1500
-150+100µm				
-100+75µm				

3.4. Analysis Techniques

3.4.1 Proximate Analysis

Determination of moisture content: Loss in weight of coal caused by heating of coal sample for one hour at 105˚C. A known amount of finely powdered coal sample is kept in a silica crucible and heated in a muffle furnace at 105-110˚C for one hour. There after the crucible is taken out, cooled in a desiccator and weighed. The percentage of moisture is given by

$$\% \text{ moisture in coal} = \frac{\textit{Loss in weight of coal}}{\textit{Weight of coal initially taken}} \times \mathbf{100}$$

Analytical techniques are used to measure the properties of the coal. It is very important to determine that for what purpose coal is being used such as for coking, electricity production and steel making etc. The percentage of moisture contents varies as geological structure, age, location and other condition varies.

Determination of Volatile Matter: Loss in weight of moisture free powdered coal when heated in a crucible fitted with cover in a muffle furnace at 950˚C for 7 minutes.

$$\% \text{ volatile matter} = \frac{\textit{Loss in weight of moisture free coal}}{\textit{Weight of moisture free coal taken}} \times \mathbf{100}$$

Ash content: It is the weight of remnant obtained after combustion of a weighed quantity of coal in an open crucible (i.e., in the presence of air) at 750˚C in a muffle furnace till a constant weight is achieved.

$$\% \text{ ash in coal} = \frac{\textit{Weight of residue ash formed}}{\textit{Weight of coal initially taken}} \times \mathbf{100}$$

There are two types of ash.

- Fly ash: is treated before disposing of. It is a very fine, powdery material composed mostly of silica made from the burning of finely ground coal in a boiler.
- Bottom ash: Can be directly disposed of. It is a coarse angular ash particle that is too large to be carried up into the smokestacks so it forms in the bottom of the coal furnace. It can be calculated on air dry basis or on oven dry basis. In this study, Lalo coal has high ash content which decreases the calorific value of coal.This study was carried out according to ASTM (American Society and Testing Material) standard. Ash exists in form of fly and bottom ash, fly ash obtained after the processing, but in present case bottom ash exist which is under consideration to mitigate into the lowest level.

Determination of Fixed Carbon: is determined percentage of substance that was lost during the testing for Volatile matter, moisture, and ash.

Weight % fixed carbon = 100- (% moisture+% ash+% volatile matter)

Calorific Value

The amount of heat produced by burning one unit mass of fuel is known as the calorific value. The coal's calorific value is determined using the bomb calorimeter. A sample of coal is put into the bomb calorimeter's crucible and volt battery is connected with electrodes and current is flowing through circuit. As soon as the combustion begins, the temperature is recorded. The heat that is produced raises the water's temperature, and the temperature is again recorded along with the calorific value.

CHAPTER FOUR

4. RESULT AND DISCUSSIONS

4.1 Evaluation of experimental results

In flotation, the surface characteristics of materials are controlled by and subjected to the influence of certain controlling agents. These flotation reagents are collectors, frothers, promoters, modifiers, or depressants (or any combination of them). The hydrophobic nature of the coal surface requires a broad spectrum of chemicals to be used in coal flotation to increase the floatability of coal particles (Kondratev & Khamzina, 2024). The hydrocarbons, such as oils and related substances are attracted to hydrophobic surfaces. They preferentially adsorb coal and make it more hydrophobic. This enhances the selectivity between coal particles and mineral materials and enhances coal recovery (Reza et al., 2007). A few of the oil collectors that have been used for coal flotation are fuel oil, creosote, and kerosene, which are all non-polar. They are added to maximize the strong relationship between the surface of coal and air bubbles (Kadagala et al., 2021b). Frothers reduce pulp phase bubble instability, generate a stable froth that provides conditions that enable selective draining of the gangue entrained in the froth, and enhance kinetic velocity (Wills, 2011). In this study, the effectiveness of sulfur and ash removal from the coal sample was enhanced using kerosene oil and n-octanol as a collector and frother, respectively. The raw coal samples before flotation and after combustion; results are shown in Table 2 and Table 3, respectively. Whereas the total coal flotation experimental and summary of the data and results are demonstrated on Table 4.

Table 2: Ash percentage result before coal flotation

Particle size (µm)	Mass of Crucible (g)	Mass of Concentrate before combustion (g)	Mass of Crucible and Concentrate before combustion (g)	Mass of Crucible and Ash Contents after combustion (g)	Mass of Ash contents (g)	Mass of clean Coal after combustion (g)	Ash (%)
-250+150	14.7388	1	15.7388	15.0085	0.2697	0.7303	26.97
-150+100	20.4283	1	21.4283	20.6890	0.2607	0.7393	26.07
-100+75	30.1731	1	31.1731	30.4306	0.2575	0.7425	25.75

Table 3: Raw coal sample assay result after combustion

Particle size (µm)	Mass of Concentrate (g)	Mass of available coal (g)	Assay (%)
-250+150	100	73.03	73.03
-150+100	100	73.9	73.9
-100+75	100	74.1	74.1

Weight of concentrate is the mass of the concentrate obtained after flotation while assay of concentrate is the percentage of pure (clean) coal in the concentrate obtained from combustion (raw coal feed). It is calculated as:

$$\textbf{Assay of concentrate} = \frac{\textit{Weight of pure Coal in concentrate}}{\textit{Weight of Concentrate}} \times 100$$

Table 4: The total coal flotation experimental results after dried

Sample test	Size (µm)	Feed (g)	Collector dosage (ml)	Frother dosage (ml)	Mass concentrate (g)	Mass of tailings (g)
LT1	-250+150	100	7	4	33.5	66.5
		100	6	4	31	69
		100	5	4	33.5	66.5
LT1	-150+100	100	7	4	34	66
		100	6	4	33.6	66.4
		100	5	4	31.6	68.4
LT1	-100+75	100	7	4	47	53
		100	6	4	46.9	53.1
		100	5	4	42	58
LT2	-250+150	100	7	4	33.2	66.8
		100	6	4	32.7	67.3
		100	5	4	30.8	69.2
LT2	-150+100	100	7	4	35	65
		100	6	4	32.9	67.1
		100	5	4	31	69
LT2	-100+75	100	7	4	50.3	49.7
		100	6	4	48.1	51.9
		100	5	4	43.7	56.3
LT3	-250+150	100	7	4	33.9	66.1
		100	6	4	33.3	66.7
		100	5	4	33	67
LT3	-150+100	100	7	4	35.9	64.1
		100	6	4	34.5	65.5
		100	5	4	30.8	69.2
LT3	-100+75	100	7	4	51.7	48.3
		100	6	4	48.6	51.4
		100	5	4	44.2	55.8

Where, LT indicates Lalo's coal trial

4.2. Effect of particle size on ash

The reduction of ash contents from the coal samples was estimated by keeping the collector dosage and varying the particle size as -100+75µm, -150+100µm, and -250+150µm, respectively. Smaller particle sizes of coal tend to result in more complete combustion and lower ash content in the resulting combustion by-products. This is because the finer particles are more easily mixed with air or oxygen, resulting in more thorough combustion and less unburned material remaining. Smaller particles also tend to have a higher surface area-to-volume ratio, which allows to faster ignition and more complete combustion (Reza et al., 2007). This reduces unburned carbon residue in ash and thereby reduces total ash yield. For example, small particle sizes in furnace-blend combustions lowered residue unburned carbon in ash by 33–52% relative to coarse particles.Improved combustion also minimizes ash-forming mineral retention in char matrices. The results showed that decreasing particle sizes are increase the ash reduction rate.This is influenced by several interconnected factors related to combustion efficiency, mineral detachment, and pore structure dynamics.The variations in ash values among different size fractions are believed to be due to the different combustability of the minerals as shown Table 5 and Table 6, respectively.

Table 5: Ash percentage result after coal flotation

Size (µm)	Collector (ml)	Frother (ml)	Mass of Crucible (g)	Mass of Concentrate before combustion (g)	Mass of Crucible & Concentrate before combustion (g)	Mass of Crucible & Ash Contents after combustion (g)	Mass of Ash contents (g)	Mass of clean Coal after combustion (g)	Ash (%)
-250+150	7	4	55.4224	1.00	56.4224	55.6840	0.2616	0.7384	26.16
	6	4	39.4407	1.00	40.4407	39.7034	0.2627	0.7373	26.27
	5	4	52.6484	1.00	53.6484	52.9144	0.266	0.734	26.6
	7	4	35.5456	1.00	36.5449	35.8067	0.2618	0.7382	26.11
	6	4	41.7336	1.00	42.7336	41.9959	0.2623	0.7377	26.23
	5	4	38.7515	1.00	39.7515	39.0170	0.2655	0.7345	26.55
	7	4	35.5455	1.00	36.5455	35.8065	0.261	0.739	26.1
	6	4	38.6473	1.00	39.6473	38.9094	0.2621	0.7379	26.21
	5	4	38.7517	1.00	39.7517	39.0158	0.2641	0.7359	26.41
-150+100	7	4	55.4023	1.00	56.4023	55.6549	0.2526	0.7474	25.26
	6	4	38.7359	1.00	39.7479	38.9896	0.2417	0.7583	25.37
	5	4	35.5361	1.00	36.5371	35.7931	0.256	0.744	25.7
	7	4	35.5453	1.00	36.5453	35.7975	0.2522	0.7478	25.22
	6	4	52.6299	1.00	53.6299	52.8831	0.2532	0.7468	25.32
	5	4	38.6626	1.00	39.6626	38.9175	0.2549	0.7451	25.49
	7	4	55.4021	1.00	56.4021	55.6540	0.2519	0.7481	25.19
	6	4	38.7357	1.00	39.7357	38.9881	0.2524	0.7476	25.24
	5	4	14.7449	1.00	15.7449	14.9987	0.2538	0.7462	25.38
-100+75	7	4	39.4275	1.00	40.4275	39.6504	0.2229	0.7771	22.29
	6	4	41.7180	1.00	42.7180	41.9502	0.2322	0.7678	23.22
	5	4	44.0775	1.00	45.0775	44.3179	0.2404	0.7596	24.04
	7	4	44.0923	1.00	45.0923	44.3075	0.2152	0.7848	21.52
	6	4	20.4355	1.00	21.4355	20.6655	0.23	0.77	23
	5	4	30.1839	1.00	31.1839	30.4220	0.2381	0.7619	23.81
	7	4	14.7450	1.00	15.7450	14.9459	0.2009	0.7991	20.09
	6	4	41.7178	1.00	42.7178	41.9428	0.225	0.775	22.5
	5	4	20.4352	1.00	21.4352	20.6721	0.2369	0.7631	23.69

Table 6: Summary of the data and results

Sample test	Size (µm)	Collector dosage (ml)	Frother dosage (ml)	Mass concentrate (g)	Mass of available coal (g)	Assay (%)	Recovery (%)	Grade (%)
LT1	-250+150	7	4	33.5	24.7364	73.84	33.87	73.84
		6	4	31	22.8563	73.73	31.3	73.73
		5	4	33.5	24.589	73.4	33.67	73.4
LT1	-150+100	7	4	34	25.4116	74.74	34.39	74.74
		6	4	33.6	25.4789	75.83	34.48	75.83
		5	4	31.6	23.5104	74.4	31.81	74.4
LT1	-100+75	7	4	47	36.5237	77.71	49.29	77.71
		6	4	46.9	36.0098	76.78	48.6	76.78
		5	4	42	31.9032	75.96	43.05	75.96
LT2	-250+150	7	4	33.2	24.5082	73.82	33.56	73.82
		6	4	32.7	24.1228	73.77	33.03	73.77
		5	4	30.8	22.6226	73.45	30.98	73.45
LT2	-150+100	7	4	35	26.173	74.78	35.42	74.78
		6	4	32.9	24.5697	74.68	33.25	74.68
		5	4	31	23.0981	74.51	31.26	74.51
LT2	-100+75	7	4	50.3	39.4754	78.48	53.27	78.48
		6	4	48.1	37.037	77	49.98	77
		5	4	43.7	33.2950	76.19	44.93	76.19
LT3	-250+150	7	4	33.9	25.0521	73.9	34.3	73.9
		6	4	33.3	24.5720	73.79	33.65	73.79
		5	4	33	24.2847	73.59	33.25	73.59
LT3	-150+100	7	4	35.9	26.8568	74.81	36.34	74.81
		6	4	34.5	25.7922	74.76	34.9	74.76
		5	4	30.8	22.9829	74.62	31.1	74.62
LT3	-100+75	7	4	51.7	41.3135	79.91	55.75	79.91
		6	4	48.6	37.665	77.5	50.83	77.5
		5	4	44.2	33.7290	76.31	45.52	76.31

4.3 Effect of Collectors on Ash recovery

Hydrocarbon oils have an affinity for hydrophobic substances, such as coal surfaces. They selectively adsorb on the coal and increase its hydrophobicity. This increases the selectivity between coal particles and mineral materials and enhances coal recovery. In the coal flotation, non-polar oils such as kerosene, fuel oil and creosote have been used as collectors. The purpose of these collectors is to encourage air bubbles to adhere firmly to the coal surface (Mdoe & Anupam et at., 2021). The flotation behavior of the coals using various collectors may change by many factors such as type and size of collector molecules, the type of bonding of collector, the structure of reagents, mixing ratio of reagents, collector electrical effect, and collector dispersion. In this study, the improvement of the ash recovery of Lalo coal was investigated by using kerosene as collector. The concentrations of collectors varied in the range of 5-7 ml per100 gm of coal at 1500 rpm impeller speed. According to this study, ash reduces with the increase of kerosene concentration.

4.4. Proximate, Sulfur and Caloric Value Results

Table 7 displays the results of the Lalo coal sample's proximate, sulfur, and calorific values. A useful technique for enhancing treated coal is the froth flotation method, which uses a collector dose of 7 ml and particle sizes between -100 and 75 μm. After beneficiation (froth flotation), the coal's quality was higher than it was before beneficiation. Results of analysis show ash content and total sulfur content were reduced from 25.75% to 20.09%, and 0.47% to 0.21% respectively. Caloric value is the amount of chemical energy in coal released as heat energy during combustion and used to determine coal rank. The result analysis shows caloric value of coal samples is increased to a value of 3850.85 Cal/g to 5393.80 Cal/g. This demonstrates that using the froth flotation technology for beneficiation is a suitable way to raise the coal's calorific value. According to its ash content coal is classified in to three categories, low (less than 8%), medium (8-15%) and high ash coal (more than 15%) (H.Wood et al., 1983). The quality analysis results show an ash content of Lalo's coal is high. The increase of ash content led to minimizing the combustion capacity, influences combustion effectiveness, maximizes transport, and causes large slagging. According to its total sulfur, coal is classified into three, low (less than 1%), medium (1-3%) and high sulfur coal (more than 3%). That indicates that the study coal samples are classified in to low sulfur coal.

Table 7: Proximate, Sulfur and caloric value results

Area	**Coal**	**Quantity**	**Proximate analysis (%)**				**Sulfur content (%)**	**Caloric value (Cal/gm)**
			Ash content	**Volatile matter**	**Moisture**	**Fixed carbon**		
Lalo coal district	Raw	1	25.75	32.83	15.26	26.16	0.47	3850.85
	Treated	1	20.09	37.40	3.45	39.07	0.21	5393.80

The trends in the quality of raw coal and after coal flotation are presented in Figures 6, Figure 7 and figure 8. Figure 6 illustrates how the fixed carbon content of coal increased significantly during flotation, providing a ballpark estimate of the coal's heating value. While the volatile matter content rose, the moisture content fell. Coal with greater volatile matter content has a lower rank and more flammable gases, which immediately reduces the quantity of fixed carbon and, as a result, lowers the coal's heating value and increases the staying time in storage rooms**.** In addition, there was a reduction in the ash content of coal after flotation from 25.75% to 20.09%. Furthermore, as Figure 7 illustrates, there was a notable rise in the heating value of coal, which went from 3850.85 to 5393.80 Cal/g. The concentrate yield of 51.7% was obtained in this study by using reagents. Kerosene oil as a collector in coal flotation can improve the floatability of low-rank coal (Shi et al., 2019), and the sulfur content of coal decreased from 0.47% to 0.21%, as shown in Figure 8.

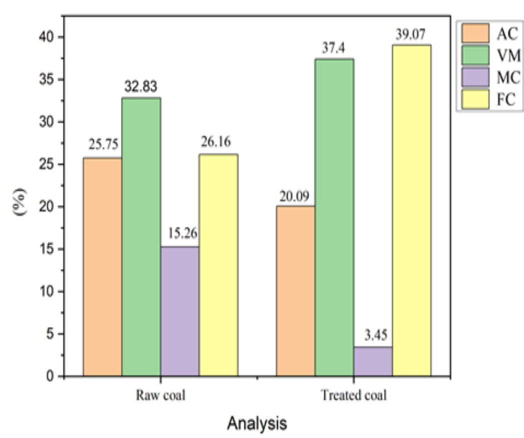

Figure 6: The comparison of before and after coal flotation based on ash, moisture, volatile and fixed carbon content

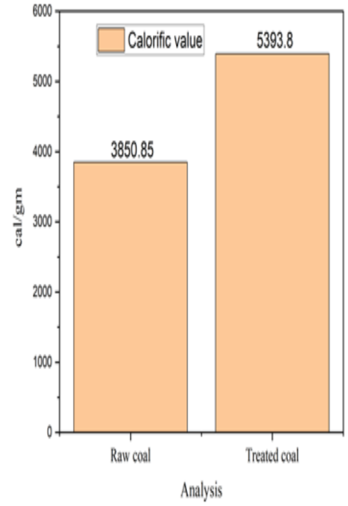

Figure 7: The comparison of before and after coal flotation based on calorific value

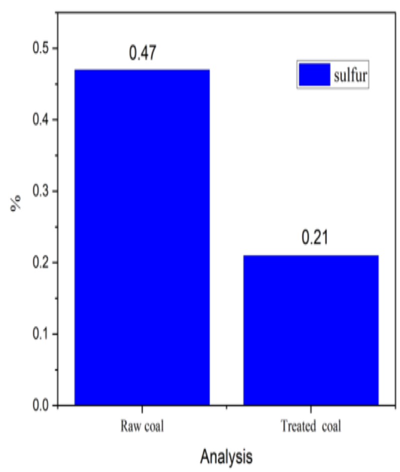

Figure 8: The comparison of before and after coal flotation based on sulfur content

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Coal samples taken from the Lalo district lignite coalfield were sapropelic, and flotation characteristics were determined for the size fractions and collector dosages separately. In these experimental findings, the particle sizes of the sample and collector dosage have a considerable effect on the removal of the ash from the lignite. The following results have been drawn out of this study:

(1) The effect of major parameters such as, particle size, and collector dosage was studied to remove ash associated with coal. All these two factors are important for the maximum reduction of ash, but the particle size has a significant impact other than collector dosage.

(2) Because of the properties of washability and hydrophobicity, large coal particles exhibit low flotation characteristics. The increase in particle size lowers the reduction rate of ash. It has been shown that the size of -250+150μm has a low ash rate.

(3) Hence, according to the result obtained from the experiments of froth flotation in which the parameters were adjusted to -100+75 μm particle size and collector dosage (7 ml) and frother dosage (4 ml), the quality of coal was enhanced later in flotation, resulting in an increase in energy value for raw coal (3850.856 Cal/gm) and treated coal (5393.80 Cal/gm), and the sulfur and ash content reduced from 0.47% to 0.21% and 25.75% to 20.09% for treated coal, respectively, which has been considered the best fitting conditions of parameters for the upgradation of Lalo coal. This study reveals that froth flotation reduces ash and sulfur from fine coal.

5.2. Recommendations

This study focused on employing flotation techniques to separate the ash content from coal output, altering the impacts of coal particle size, and using kerosene dose as a collector. Future studies on the technology of coal separation from ash should concentrate on the effects of other variables, such as air flow rate, collector type and dosage, frother type and dosage, coal slurry pH, and time variation.

By optimizing particle size to -100+75µm and by increasing recovery of such particles in froth product, kerosene oil was used as collector in this work. This reduced the load of ash from coal and provided a condition under which hydrophobic particles were permitted to adhere to air bubbles. However, an n-octanol frother was used to generate a high number of small air bubbles in order to enhance the surface area of air pumped into the flotation machine during coal flotation. It is advised to use methyl isobutyl carbinol rather than n-octanol in the future. Additionally, because column flotation is scalable and efficient at recovering coal, it is advised to utilize it in conjunction with reflux classifiers to recover coarse particle size.

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