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Addis Ababa University
Addis Ababa University Institute of Technology
Center for Ethio-Mines Development

Beneficiation of Blended Coal by Froth flotation Technique, In The case of Kripto Coal Mining and Chemicals PLC Elasanchano Woreda Konta Zone South West Region of Ethiopia

A project: Submitted to Addis Ababa University, Addis Ababa Institute of Technology Center for Ethio-Mines Development in partial fulfillment of the requirement for the degree of masters of Engineering in Mineral process Engineering

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March 2025
Addis Ababa Ethiopia

Approval Page

This is to certify that the project report prepared by Ewunetu **Beneficiation of Blended Coal by Froth flotation Technique, in the case of Kripto Coal Mining and Chemicals PLC Elsanchano woreda konta zone South west region of Ethiopia** submitted in the partial fulfillment of the requirements for the degree of Masters of Engineering in Mineral process Engineering compiles with the regulation of the university and meets the accepted standard with respect to originality and quality.

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Declaration of Originality

I Declare that the project Beneficiation of blended coal by froth flotation technique, in the case of Kripto coal mining and chemicals plc elsanchano woreda konta zone south west region of Ethiopia has been carried out by me under the supervision of Mulugeta sisay (PhD) and Mamaru Genetu (MSC) Center for Ethio –Mines Development, AAiT in the year 2025 as part of master

Program Mineral process Engineering I further declare that this project has not been submitted to any other university or institution anywhere for the award of any degree, diploma and certificate.

Name Ewunetu Mitku Abebe

Date of submission ---------------------------------

Signature --

Acknowledgment

First, I would like to express my heart full thanks to my almighty god: who is the basis of for all the successful progress of my life as a whole and this project as a particular. I want to express deepest gratitude to my advisor Mulugeta sisay (PhD), and co-advisor, Mr. Mamaru Genetu (MSc) for their valuable support, encouragement, guidance, and valuable criticism during this project work. I acknowledged Addis Ababa University institute of technology Center for ethio-mines development excellent hospitality and invaluable support during the entire journey of study. I want to give genuine gratitude to minister of mines for the chance to study master’s degree,

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Abstract

Beneficiation of blended coal in the case of Kripto coal mining and chemicals plc located Elasanchano woreda konta zone, south western part of Ethiopia using kerosene as a collector n-octanol as afrother sodium silicate as a depressant with aeration speed of 1850 r/pm to facilitate the formation of small bubble enhance the calorific value of blended coal in the three flotation parameters studied in this project. which is particle size, frother dosage and flotation time is investigated. The optimal particle size we get maximum combustible recovery and quality is +125+-250 µm particle size which have 35.699% recovery and its heating value measured in boom calorimeter is 6,047.5781Ca/gram. The optimal frother dosage we get maximum recovery and grade is 6ml of n-octanol which have 65.157% recovery and its heating value is 6,412.7735 Ca/gram. The optimal flotation time we get high combustible recovery and quality of coal is 10 minute which have 70.426% of recovery and its calorific value is 5,894.4779 Cal/gram. Generally, froth flotation technique is good for environmentally friend method for the reduction of sulfur content in coal which reduce the release of SO_2 gas cause for the formation of acid rain and health risks including lung cancer in humans. This project reduces the sulfur content of blended coal 0.68% to 0.44%. So, froth flotation is an appropriate method for the enhancement of heating value and proximate and ultimate characteristics of coal by removing the impurities from coal.

Key words: - Beneficiation, Froth flotation, Optimal, Collector, Blended coal, Impurities, Depressant

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List of Abbreviation and Acronyms

MIBC --Methyl iso butyl carbinol

DM--Dense media separation

MJ/t--Mega joule per ton

EGS---Enhanced gravity separation

ASTM---American Society for Testing and Materials

PPM---Parts per million

HGMS---high-gradient magnetic separators

CIAB--Coal Industry Advisory Board

Na_2SiO_3 --Sodium silicate

MIDI--- Mineral industry development institute

Ma---megaannum, a unit of time equal to one million years.

CHAPTER ONE

1.Introduction

1.1 Background of The Study

Coal is a sedimentary rock that primarily consists of organic materials with trace amounts of mineral constituents. The degree to which the original plant material is changed determines the composition and properties of coals. The various types of coal lignite, sub-bituminous coal, bituminous coal, semi-anthracite, and anthracite. The major unit operations in coal beneficiation include dewatering, size classification, homogenization, and size reduction (Melo & Laskowski, 2005).

Blended coal is a system that harmonizes two or more different coals with different qualities with or without the same origin. A correct blending procedure can reduce the emission of dangerous gases and significantly lower the cost of repairing and maintaining power plant boilers and mills. Proper blending increases boiler efficiency, which results in significant financial savings. Since the 1980s, scientific studies on coal blending have increased significantly, both theoretically and practically. Through the use of blending procedures, coal exporters and operators of mine-to-mouth power plants that source coal from one or more coal mines were able to obtain the desired quality coal. Blending trends were mostly seen in countries that import coal, such as the Netherlands, and countries that produce and export coal, such as Australia and South Africa. With time, mine-mouth plant operators who received coal from one or more coal mines started efficient coal blending procedures (Yörükoğlu, 2017).

Coal blending, in its most fundamental sense, involves the combination of various coal types to create a mixture that combusts efficiently to generate heat and/or electricity. In the past, plant operators focused on using as much of the most affordable and readily available coal as possible while reducing the amount of higher-quality coal in order to create a fuel mix that would produce electricity without causing harm to the plant. Although cost remains a significant concern, the evolution of coal markets and changes within the power sector have prompted many plants to evaluate additional factors when determining an acceptable coal blend. Operators must assess which parameters hold the greatest importance for their specific facilities. For instance, certain plants may prioritize moisture content over ash content and adjust their blending practices accordingly. Blending is predominantly determined on a case-by-case basis, and in most instances, the choice of blend is made by the plant operator relying on their personal experience and sound judgment, rather than through a standardized process (Sloss, 2014).

The method of blending may occur at various stages in the mine site, during transportation, or at the power plant. The majority of coal cleaning techniques involves gravity separation techniques though flotation is frequently employed to process the fine fractions in the case of metallurgical coals among these; the cleaning step is the one that determines the overall coal preparation cost. Blended coal beneficiation is the process of enhancing the quality of coal using the froth flotation technique to improve its performance in power generation, ultimately resulting in economic and environmental benefits.

Froth flotation is a common separation technique in the mining sector that separates valuable materials from unwanted gangue by utilizing variations in particle surface characteristics. The degree to which the particles to be floated are hydrophobic achieved by the adsorption or chemisorption of collectors onto the particle surface determines the separation efficiency. The amount of reagent adsorbed onto the solid particle surface determines how hydrophobic the particle is, and this is known to have an impact on flotation recovery (Hadler et al., 2005).

Froth flotation uses the difference in wettability between different minerals to separate water-repellent hydrophobic particles from easily wettable hydrophilic particles. When a mixture of hydrophilic and hydrophobic particles is suspended in water and air is bubbled through it, the hydrophobic particles tend to adhere to the air bubbles and rise to the top. This process creates a foam layer that is rich in hydrophobic minerals, which can then be separated and collected. In contrast, hydrophilic particles are much less likely to stick to the air bubbles, so they remain in suspension and are flushed away (Fuerstenau & Urbina, 2018).

The process of froth flotation may become more difficult as coal oxidizes and loses its inherent hydrophobicity. The coal oxidation process has three steps. Coal-oxygen functional groups with acidic characteristics are formed on the coal surface in the first stage. In the second step, the coal's organic materials are converted to humic or hydroxyl carboxylic acids. In the third stage, humic acids are broken down into water-soluble acids. The coal surface develops these functional groups, which decrease the coal's inherent hydrophobicity. Acidic functional groups are more prevalent in low-rank and oxidized coals. As a result, the coal particles' zeta potential, or surface charge, decreases. With increased oxidation of coal, the contact angle falls and the zeta becomes more negative. Due to a lower difference in hydrophobicity, this alteration makes it more difficult to separate from comparable hydrophilic gangue minerals (Otsuki & Miller, 2019). Different chemical reagents, including as collectors, frothers, surface modifiers, and pH regulators, are frequently needed for the froth flotation process. Frothers are crucial in establishing the stability and mobility of the froth phase in addition to the distribution of bubble sizes.

Collectors are used in froth flotation to selectively adsorb onto particle surfaces, forming a non-polar, hydrophobic monolayer of hydrocarbons. This increases the contact angle, allowing bubbles to adhere to the surface (Fuerstenau & Urbina, 2018).

1.2 Description of the Study Area

1.2.1 Location

The konta zone Elasanchano woreda is found in south western part of Ethiopia. It is located 435km distance from the capital city of Ethiopia (Addis Ababa) and has an aerial coverage of 12. 9km^2. The 360km road is accessed by asphalt that starts from Addis Ababa and continue up to Jima. The remaining 75km from Jima through Dedo, Delbi, kirara is all weather gravel road that cross the coal mine site area almost at equal part. The nearest small town Chida contains both electric power and water supply and located at 3km from the coal mine site area.

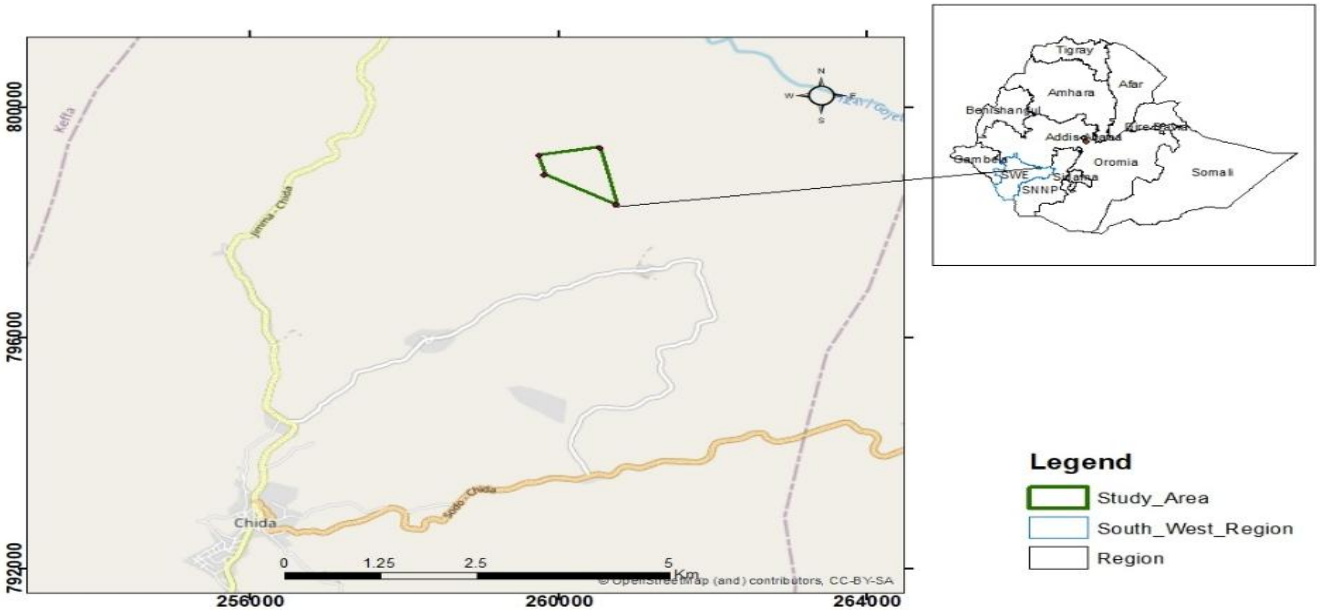


Figure 1 Show location of the study area

1.2.2 Climate Condition

The study area exhibits a semi-arid (Kolla) climate due to its elevation ranging between 1,040 and 1,610 meters above sea level. Annual rainfall is relatively low, varying from 200 to 300 mm, while mean temperatures range from 20 to 27°C with noticeable seasonal variations. The hottest period occurs from February to May, particularly in lower-lying areas such as the Gojeb River basin in the northern part of the region. The rainy season extends from June to September, accounting for most of the annual precipitation. From October to January, milder spring-like conditions prevail. Higher elevation areas, including Ofa Gola, Beke Bela, Mulu Guda, Womba, Suti Beso, and Bidate Beduda, experience more temperate conditions compared to the hotter lowlands (Kripto, 2017).

1.3 Statement of the Problem

Coal is one of the most important sources of energy in the world used in the cement and steel industry. Coal’s quantity and performance in different applications are strongly impacted by quality standards and market demand, which also affects coal's price. Various coal specifications and quality results various performance outcomes, underscoring the significance of coal quality for its commercial viability. The different types of Blended coal at pulverized coal-fired power plants is increasingly common among electric utilities aiming to reduce costs, fulfill SO_2 emission regulations, and improve combustion behavior (Salmi et al., 2020).

However Southwest Ethiopia's Konta Zone, Elasanchano woreda Chida locality contains substantial amounts of low-grade coal deposit. At the moment, Kiripito Mining and Chemicals PLC produce blended coal by mixing of different Gross Caloric Values (GCV) of coal (high calorific value of coal with low calorific value) of coal without any sort of washing or cleaning procedure, then directly deliver to the cement factories. But customers are not satisfied with the use of this blended coal or other industries are not interested to use this coal due to the anomalities of quality. Because of high ash and sulfur content, which lowers its calorific value, increase maintenance cost and pollution of the environment when burned.

The limitations of the current coal processing techniques lead to significant losses in potential energy production and economic value. Therefore, a technique that can remove these impurities is greatly needed to improve the overall quality of the coal. Although the froth flotation technique is a viable solution, its effectiveness is dependent on a number of operational factors but in this project, particle size, frother dosage, and time are being studied to optimize the removal of impurities from blended coal.

1.4 Research Question

Q_1. What are the optimal frother dosages to maximize blended coal recovery and quality?

Q_2. What are the optimal particle size and time to maximize both the grade and recovery of blended coal?

Q_3. What is the effect of variation particle size, time and frother dosage on recovery and quality of blended coal?

Q_4. What is the effect of physicochemical properties (volatile matter, ash content and moisture content) on the heating value of coal?

Q_5. What is the effect of particle size on particle-bubble contact and attachment and detachment during froth flotation of blended coal?

Q_6. what is the weight of coal recovered and ash remove from the raw Blended coal in each flotation parameter?

1.5 Objective of the study

1.5.1 General Objective

The general objective of the study is to improve the calorific value of blended coal by the application of froth flotation technique.

1.5.2 Specific Objective

- To evaluate the impact of particle size and flotation time on the quality and recovery of blended coal.
- To evaluate the effectiveness of frother dosage improving calorific value of blended coal.
- Examine the blended coal's physicochemical characteristics before and after treatment by flotation technique.
- Quantify the heating value of the blended coal before and after treatment by froth flotation technique.

1.6 Scope of the study

The scope of the project was investigation of flotation parameters including particle size, frother dosage and time. To achieve this Blended coal sample were collected from the stock of Kripto coal mining and chemicals PLC. With GPS points of Easting 260547.102, 260749.546, 259806.996, 259747.091 and Northing 799291.828, 798300.519, 798827.127, 799166.452 Proximate and ultimate analysis were conducted to evaluate the Quality improvement of coal before and after beneficiation by froth flotation technique. Additionally check the effectiveness of froth flotation technique in terms of increase the heating value of coal by reducing impurities such as ash and sulfur.

1.7 Significance of the study

The significance of this study is increasing the quality and usability of local coal product in Ethiopia. By investigating froth flotation parameter like particle size, frother dosage and time. The study reducing impurities such as ash and sulfur. Which increase the heating value of blended coal. This improvement is important for making the coal more suitable for energy production and address the energy demand in the country. The study also important in environmental concern by reducing the emission of SO_2 that cause acid rain health risk in humans. Promote cleaner energy practice and environmental sustainability in the region. The study also shows the environmental and economic benefit of coal beneficiation practice in the region and ways of appreciating the local coal resource.

1.8 Limitation of the study

The froth flotation technique is affected by several operational parameters but in this project only particle size, frother dosage and time is studied. challenging to isolate the effects of one parameter to the other. The technique reduces the impurity (does not remove all impurities). The representativeness of the stock sample is only in specific geographical area. The result cannot generalizability of the results of other region or coal types. Due to the sensitivity of froth flotation experiments operational parameters achieving optimal condition for all coal types was difficult. The different hydrophobicity nature and mineral content of coal complicate the flotation process. The method of producing blended coal in the company have limitation cannot check whether the coal particle size is equality pulverized or not this may affect the mixing technique and sampling. finally, cannot get the expected calorific value of coal.

CHAPTER TWO

2. Literature Review

2.1 Geology of the study Area

2.1.1Regional Geology

The southwestern plateau is part of the East African Rift System, influencing the Gojeb-Chida coal basins (Ministry of Mines and Energy. The region lies within a proto-rift (Ashangie) of Eocene-Early Oligocene age (Workineh et al 2012). Triassic to Cretaceous sediments are overlain by Tertiary basaltic lava flows and pyroclastics, followed by Quaternary volcanics (basalt, trachyte, rhyolite). Tertiary lacustrine and deltaic sediments host Ethiopia's main coal deposits, primarily in the west and southwest (Tigist W 2007). The Chida basin and other isolated basins follow a NE-SW trend, linked to Ashangie rift tectonics. Paleo-lake development during the Tertiary led to fluvio-lacustrine sedimentation, with coal formation in Oligocene-Miocene periods due to tectonic and volcanic influences (Kazmin, 1975).

The study area contains an estimated 9.5 million tons of coal reserves, of which 4.5 million tons have been classified as measured resources of subbituminous rank. Geophysical investigations indicate that the coal-bearing sedimentary layers have an average thickness of approximately 60 meters, suggesting significant potential for resource extraction. These findings demonstrate the economic viability of the deposit while highlighting the need for further detailed exploration to fully evaluate the reserve's characteristics and extraction potential (Bulto and Tamirat 2020; Tura and Tassew 1995; Workineh et al 2012; Genetu & Kebede 2024).

2.2 Local Geology

2.2.1 Lithologic Description

The Chida coal study area is covered by pre-rift Tertiary volcanic and sedimentary rocks. The volcanic series includes basalt and overlying trachyte, while sedimentary units consist of sandstone, coal, volcano-clastic sediments, carbonaceous mudstone, mudstone, and oil shale. These are overlain by basalt or, in some areas, directly by trachyte (Kripto, 2017).

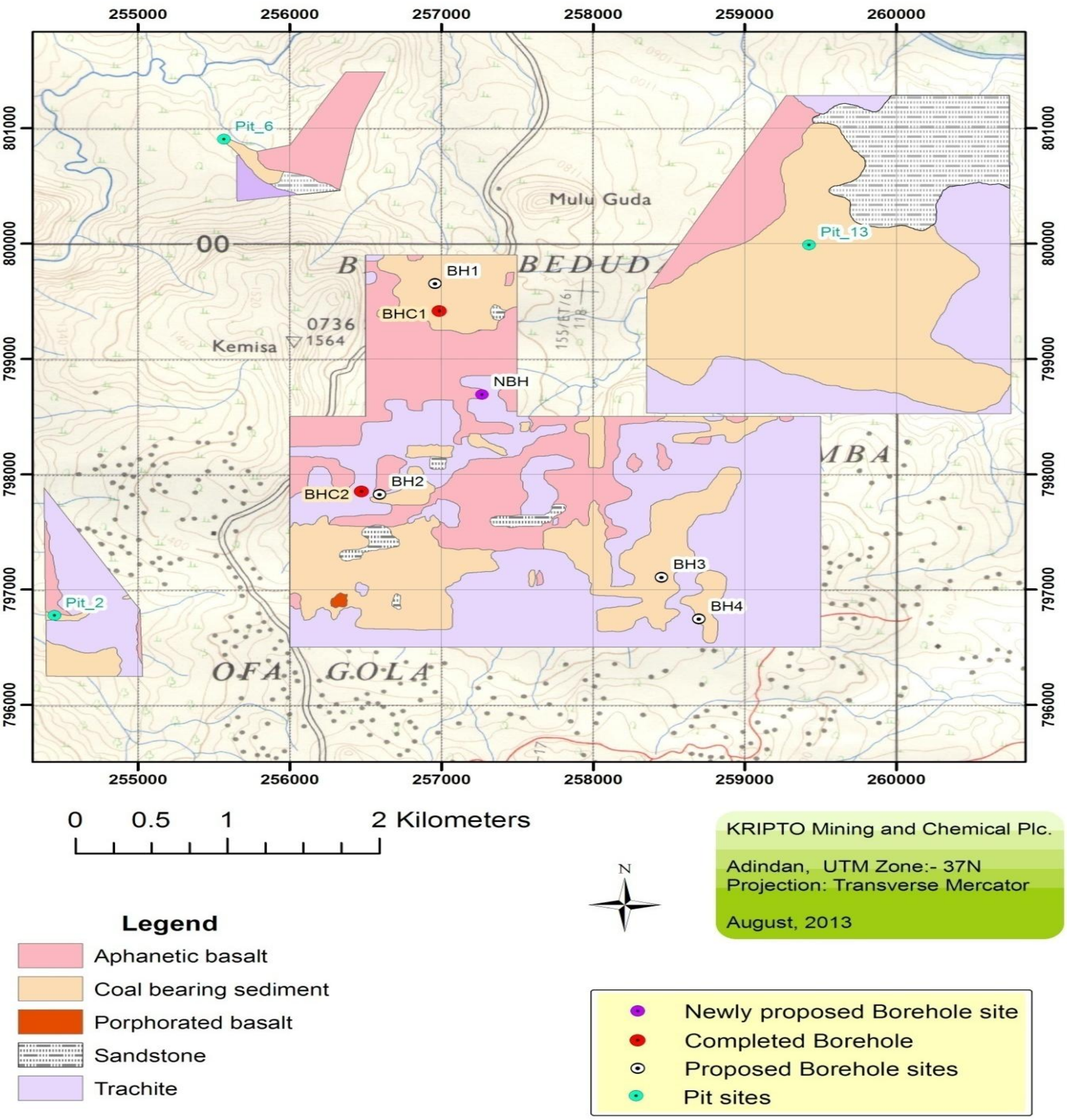


Figure 2 Geological map of the study area (Kripto, 2017).

2.2.2 Trachyte

Trachyte is mostly found at higher elevations but also contacts sedimentary units due to structures. It is light gray to white, fine-grained, moderately jointed, and deeply weathered (oxidized and kaolinized). It is intermediate to felsic, dominant in Block 2, and varies in thickness (10–100 m), trending N-S.

2.2.3 Basaltic Unit

Basalt (black to dark gray, aphanitic) dominates Blocks 1 and 4. It is massive to moderately jointed, with columnar fractures in places, and weathers into lateritic soil. Thickness ranges from 10–50 m, mainly in the eastern, western, and central parts (Workineh et al 2012; Kripto 2017).

2.2.4 Sedimentary Units

- **Sandstone**: Fine to medium-grained, varies in color (white, gray, pink, reddish-brown), with quartz and feldspar.
- **Volcano-clastic sediments**: Poorly sorted, pebble to cobble-sized, found along riverbanks.
- **Oil shale**: Dark, fissile, 0.4–0.6 m thick, often covered by volcanic rocks.
- **Carbonaceous mudstone**: Dark gray, laminated, 0.1–2 m thick.
- **Carbonaceous shale**: Dark, foliated, ~0.3 m thick.
- **Mudstone**: Gray-black, massive to fractured, 0.2–2.2 m thick.
- **Shale**: Light gray, fissile, 0.2–0.6 m thick.
- **Coal unit**: Interbedded with sedimentary and volcanic rocks. 18 pits and 12 stream sections were studied to trace coal continuity (Workineh et al 2012; Kripto 2017).

2.2.5 principle of froth flotation

Froth flotation is a process that exploits the differences in hydrophobicity among mineral surfaces to effectively separate valuable minerals from gangue materials through the use of air bubbles. In this process, hydrophobic particles adhere to the rising bubbles, resulting in the formation of a froth layer at the interface of air and water (Otsuki & Miller, 2019). Conversely, hydrophilic particles remain suspended in the slurry due to their limited attraction to the bubbles. To modify the characteristics of both the minerals and the bubbles, various reagents are introduced. Among these, frothers play a crucial role by facilitating the formation of a stable froth layer through the nucleation of small, stable bubbles. The froth itself consists of a mixture of air bubbles, solids, and water. When bubbles collide, the liquid film separating them becomes thinner and eventually ruptures, leading to bubble coalescence. The introduction of frothers mitigates the rate of coalescence, thereby enhancing the stability of the froth. The primary function of a Frother is to generate fine, stable bubbles. A Frother is composed of a polar group and a non-polar hydrocarbon radical (Otsuki & Miller, 2019). In the froth flotation process, the hydrophilic polar group interacts with the water phase, while the hydrocarbon radical interacts with the air phase. This characteristic allows certain frothers to also function as collectors due to their non-selective adsorption on both air bubbles and mineral particles, which can become hydrophobic. The addition of a small quantity of Frother can enhance the flotation of oxidized coal. The Frother adheres to the coal-water interface, providing a point of attachment for the collector. In essence, a Frother can serve as an activator. However, if the concentration of Frother exceeds a specific threshold, it begins to adsorb onto the coal surface, rendering it more hydrophilic. Consequently, the Frother can significantly cover both the bubble and coal surfaces, creating a repulsive force that diminishes coal flotation recovery (Otsuki & Miller, 2019).

An essential part of flotation is froth. The right choice of these reagents is critical to the overall flotation performance because they directly affect the properties of the froth and, in turn, affects variables related to the entrainment of unwanted particles. It is accepted those frothers: Reduce the size of bubbles; Keep the froth stable. Moreover, flotation frothers need to fulfill a few standards in order to guarantee their industrial suitability. Such as it needs to be easily distributed throughout the medium. It needs to be compatible with the quality and operation of the other reagents used in froth flotation and have an inert structure that doesn't interfere with them. It must not be impacted by variations in the flotation cell medium's pH. The valuable mineral-containing froth that has been removed must readily disengage to permit additional treatment, it needs to be affordable, readily available, and, when applied widely, not harmful to the environment (Melo & Laskowski, 2005).

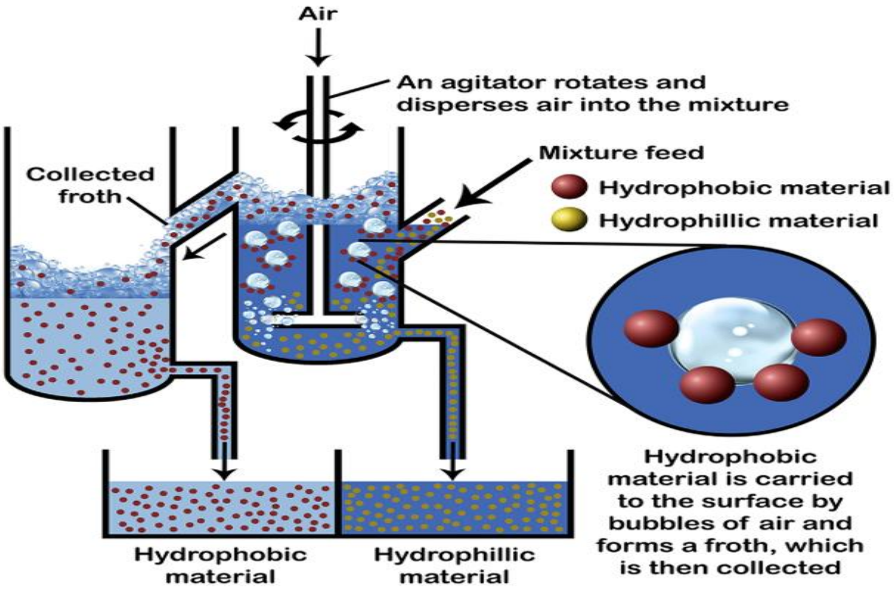


Figure 3 Shows general process of flotation (Crawford & Quinn, 2017)

Wheeler states that a tiny bubble should form on the Frother A reduced diameter directly increases the flotation rate because it will do the following: increases the likelihood that a coal particle will find a bubble to collide with by increasing the amount of bubble/constant air volume. Increase the likelihood of a bubble particle collision by straightening out the paths of the tiny particles surrounding the bubble. enhances the number of smaller bubbles that can attach to a coal particle, lowering the chance of detachment (Bhattacharya & Dey, 2008).

2.1.1 Coal Blending

In any coal seam, the quality of the coal exhibits spatial variability. Coal cannot be of consistent quality if it is not treated after mining. Even though the calorific values of coal meet the boiler's required range, any excessive fluctuation in the quality parameters lower heating value, ash, moisture, volatile matter, grindability, Sulfur, etc. may have the unintended consequence of increasing costs and polluting the environment. As noted by (Nkuna 2009) a high ash content hinders the capacity to burn, low temperatures that result in boiler trips as a result of boilers, variations in coal quality have a direct impact on plant availability, efficiency, unintended emissions, and expenses. The main goal of blending is to increase the uniformity of non-homogeneous coal in order to improve power plant performance, create an environmentally friendly system, reduce fuel costs, and prolong the life of coal reserves (Yörükoğlu, 2017).

(Zhang et al. 2012) assert that the effectiveness of coal blend firing in most power plants is significantly influenced by the expertise of the individual operators. Many operators either lack the incentive to disclose plant-specific blending information. Due to commercial legal or other considerations. In certain instances, regulatory requirements may mandate that plants report coal-related data. Nevertheless, this information is seldom made available to the public, resulting in the majority of literature reviewed being derived from either experimental academic research or commercial sources, such as utility reports, coal production statistics, or materials provided by equipment suppliers (Sloss, 2014).

As studied (Anderson and Nowling ,2014) the characteristics of coal significantly influence nearly every operational facet of a power plant, including the forced outage rate, maintenance expenses, auxiliary power needs, net plant heat rate, emissions, and the capacity to achieve full load. Upon commissioning, coal-fired power plants are typically engineered to utilize a specific type of coal. However, over time, the availability and affordability of certain coals may diminish during the plant's operational lifespan. Consequently, it is increasingly common for plants to consider the use of coals that do not align with their original design specifications. Given that coal characteristics impact nearly all aspects of plant performance and operation, it is essential to anticipate, to the greatest extent possible, the physical and economic challenges that may arise from transitioning to different coal types (Sloss, 2014).

2.1.2 Coal Flotation

Coal flotation is the difference in surface characteristics of hydrophobic coal and hydrophilic mineral substances. Coal is a highly heterogeneous substance, with its composition undergoing alterations through the coalification process, which involves the transformation of plant material into coal via diagenesis and metamorphism (Sokolovic & Miskovic, 2018). The organic and mineral components within coal exhibit distinct surface properties often reflected in their levels of hydrophobicity. Research indicates that the floatability of coal can vary significantly based on factors such as coal rank petrographic composition, oxidation degree, and particle size distribution. An examination of coal floatability in relation to coal rank was presented by (Klassen ,1963) and further elaborated upon by (Laskowski, 2001). Coals that exhibit a high level of coalification are inherently hydrophobic, as noted by (Xia et al. in 2013). Among these, high volatile bituminous coals demonstrate the greatest hydrophobic characteristics, while lignite displays comparatively lower hydrophobicity, as indicated by (Hower et al. 1984). Additionally, it has been observed that anthracite coal possesses reduced hydrophobicity, attributed to an increase in its specific surface area, according to Zhang in 2004 (Sokolovic & Miskovic, 2018).

2.1.3 The Effect of Particle Size on Flotation Kinetics

The size of particles is a critical factor in the flotation process, as it influences the mineralization of gas bubbles, the distribution of bubble sizes, and the retention of air within the system. Additionally, it impacts the stability of bubble-particle aggregates, which is indicated by the rates of particle attachment and detachment, as well as the adsorption of reagents. Different particle sizes exhibit distinct behaviors within the flotation system, which in turn affects flotation recovery and the overall efficiency of the process (Sokolovic & Miskovic, 2018).

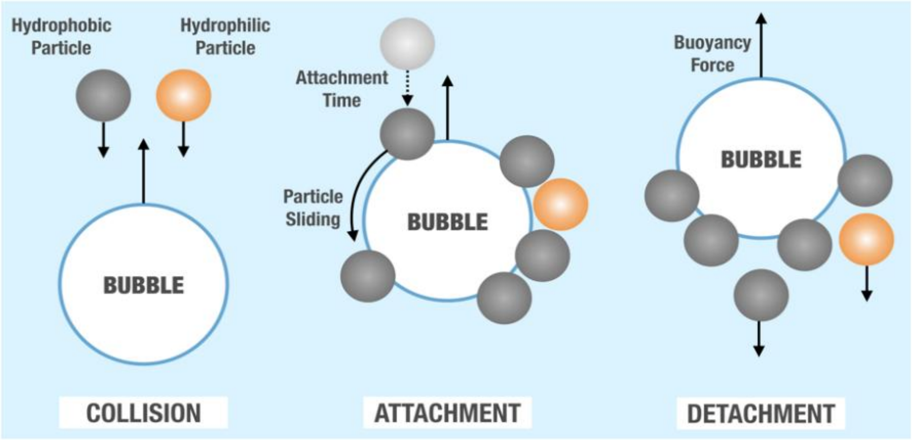


Figure 4 Shows Mechanisms of particle-bubble interaction (Sokolovic & Miskovic, 2018).

The overall likelihood of flotation, as well as the rate of flotation kinetics, is significantly influenced by particle size. The probability of collision is directly proportional to particle size, whereas the probabilities of attachment and detachment are inversely proportional to it (Sokolovic & Miskovic, 2018). Numerous investigations have been undertaken to assess the influence of particle size, shape, and the extent of particle liberation on coal flotation. For instance, (Varbanov ,1984) found that the flotation rate is significantly affected by particle size, while the impact of particle shape is comparatively less pronounced. The optimal particle size that yields the highest flotation rate and final recovery varies considerably based on operational conditions. Initially, the flotation rate increases with particle size, reaches a peak, and subsequently declines. This phenomenon can be attributed to the interplay between collision processes, which are more prevalent in smaller particles, and attachment/detachment processes, which dominate in larger particles (Polat et al., 2003).

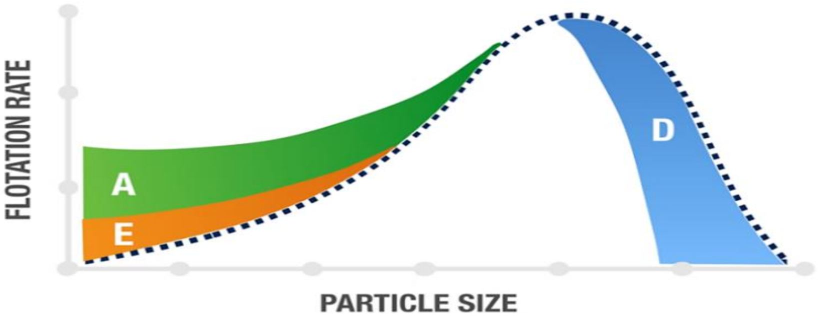


Figure 5 A schematic representation of the effect of particle size on flotation rate (Sokolovic & Miskovic, 2018).

Recently demonstrated that the ability of fine coal particles to stabilize froth depends on their hydrophobicity and proportion. The deepest and most stable froths were produced with an intermediate particle size of 74–250 µm. The highest recovery of coal to the concentrate was obtained when a combination of roughly 55% fines at 74 µm and 45% coarse particles at 250–500 µm was taken into consideration. Fine particles make bubble films in a specialized agitated column more rigid, which prevents coalescence and increases froth stability (Norori-McCormac et al., 2017).

2.1.5 The Effect of Frother Dosage on Flotation Kinetics

By stabilizing the air bubbles, frothers help the slurry stay evenly distributed and create a stable froth that is bigger than what can be eliminated before the bubbles burst. Alcohols specifically, methyl isobutyl carbinol, or MIBC and various Polyglycol are the most widely used frothers. With a kerosene collector maintained at 125 g/t, 50–200 g/t of either pine oil or MIBC used as a frother to boost the flotation yield (Ehsani & Eghbali, 2007). Figures below 6 and7 illustrate how pine oil and MIBC behave as frothers at different concentrations upon ash and sulfur content reduction. Fig 7 compares the coal recovery percentage performance of these frothers. Pine oil is more efficient than MIBC, but both frothers improved flotation yield and recovery percentage. At very low dosage of frother the air bubbles' strength was so weak that coal particles could not be carried to the froth phase, which reduced yield and recovery. Fig 6 and 7 demonstrate that, for both pine oil and MIBC, the reduction of sulfur and ash decreases. As the concentrations of frother increase, the ash reductions decrease consistently.

In coal flotation, Kimpel discovered that the flotation rate and recovery values changed when different frothers were used. Irrespective of the type of frother, increasing the dosage of the frother to increase recovery always results in less selective flotation (Ehsani & Eghbali, 2007).

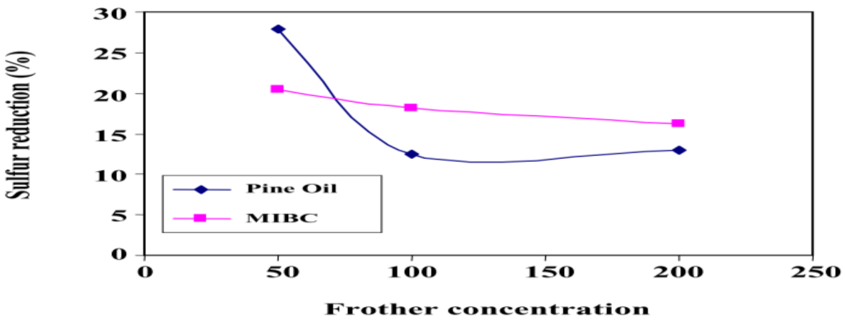


Figure 6 Effect of frother concentration on sulfur reduction (Shi et al., 2019)

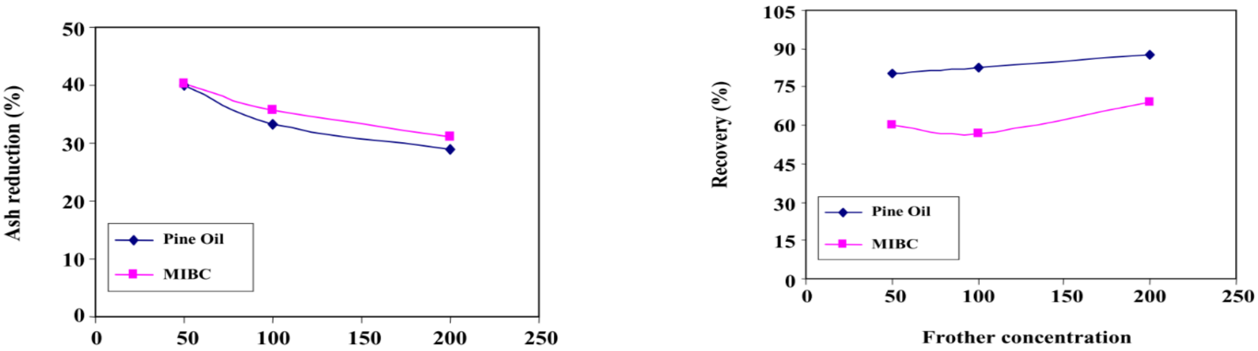


Figure 7 Effect of frother concentration on ash reduction and Effect of frother concentration on coal recovery (Shi et al., 2019)

Frother-Collector Interaction: According to Wang et al the combination of good collector with a moderate dosage of Frother resulted in improved flotation outcomes for low-grade coal, leading to enhancements in both recovery rates and coal quality (Akbari, 2009). As noted by Zhang et al. a low dosage of Frother resulted in unstable froth and insufficient interactions between bubbles and particles, ultimately causing reduced recovery rates. Insufficient Frother can lead to inadequate froth stability, which in turn reduce the recovery of valuable minerals (Akbari, 2009). Figure 8 illustrates the impact of frother (octanol) doses. It is evident that the ash content and output of clean coal first dropped and then grew as the frother dosage increased. When the frother dosage was 500 g/t, the flotation performance was at its peak. Clean coal had an ash content of 14.79% and recovery of 58.02%, respectively (Shi et al., 2019).

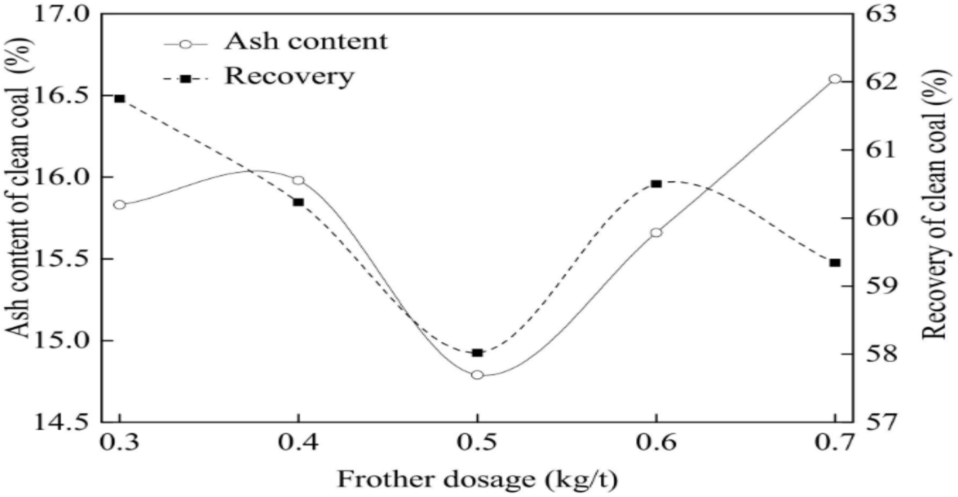


Figure 8 Effect of frother dosage on flotation performance (Shi et al., 2019).

2.1.6 The Effect of Time on Flotation

The flotation process is a popular method in the coal business for making low-grade coal useful. The flotation process's duration is one of the variables that can affect how effective this technique is. When a sample of low-grade coal was floated, the recovery and coal concentrate grade rise as the flotation period increased (Asiva Noor Rachmayani, 2015). As the floating time extended from 5 to 20 minutes, the coal recovery rise from 65% to 85%. In the same time frame, the coal concentrate's grade also improved, rising from 55% to 65%. The enhanced particle-bubble attachment and increased impurity removal from the coal are responsible for the rise in recovery and grade of the coal concentrate as flotation time increases. A longer flotation time may not always result in additional process improvements, thus it's crucial to identify the optimal time range to guarantee the most effective and economical operation (Asiva Noor Rachmayani, 2015).

Figure 9 shows the results of the timed-release flotation test. As can be shown, the yields of the tailing products from the four successive re-flotations were all below 10%, with the roughing tailing product Tr1 having the greatest yield at 73.13%. With extended flotation times, the amount of ash in the tailing products gradually decreased, indicating that coal slime was being separated from gangue minerals, which raised the grade of froth concentrate. The coal flotation tailings had a considerable amount of coal and gangue combinations that were difficult to separate directly, as evidenced by the greatest ash percentage (67.75%) in the tailing product Tr1. Low-ash products with a yield of 19.28% and an ash percentage of less than 10% could be recovered after two flotation separations. This result was consistent with the coal samples' density analysis Shown fig 7 (Tian et al., 2022).

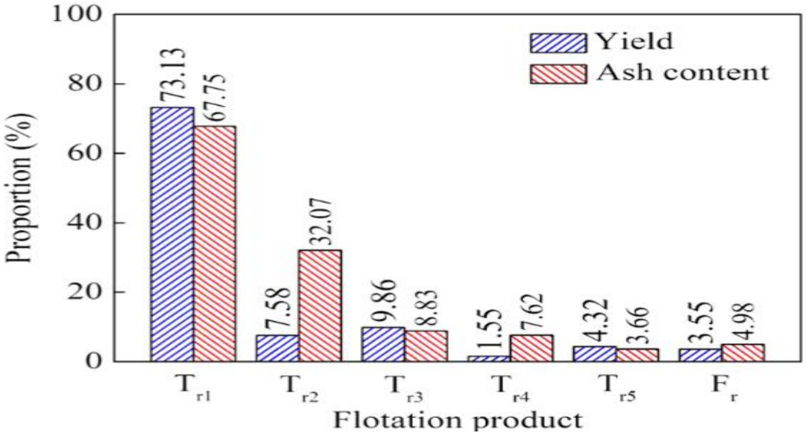


Figure 9 Timed-release flotation test results (Tian et al., 2022).

2.2. Physical Beneficiation Method of Coal

Physical beneficiation is a well-known and widely used method for removing impurities and improving the quality of coal without any chemical changes. Its main objective is to distinguish between impurities and coal by utilizing the resulting physical properties, such as the dimensions of mineral matter, specific gravity, magnetic susceptibility, and the carbonaceous components of the coal. Higher-quality coal responds well to the physical beneficiation process; however, lower-quality coal does not benefit as much. this technique has its limitations, including the elimination of only pyritic sulfur and the requirement for a larger feed size (more than 0.5 mm) for the gravity separation of coal. These factors render it unsuitable for the separation of chemically bonded minerals. Consequently, for processing lower-grade coals especially those with significant sulfur content and chemically bound contaminants within their coal matrix the physical beneficiation technique is somewhat less effective (Flotation, 2023).

2.2.1 Magnetic Separation

Pyrite is being separated from coal. Because of their very similar magnetic susceptibilities, coal and pyrite are most suitable for use in high-gradient magnetic separators (HGMS) or coal preprocessing, which may make coal mineral matter more susceptible. With pyrite liberation frequently requiring very fine grinding (e.g., below 400 mesh), high-gradient magnetic separation, which was created to improve kaolin clays by removing iron and titanium oxide impurities, seems particularly well-suited for coal desulfurization. Better selectivity is offered by wet magnetic separation techniques for the fine dry coal that has a tendency to agglomerate. High-gradient wet magnetic separation tests have so far demonstrated enhanced sulfur rejection at fine grinding as indicated fig 8(Laskowski, 1989).

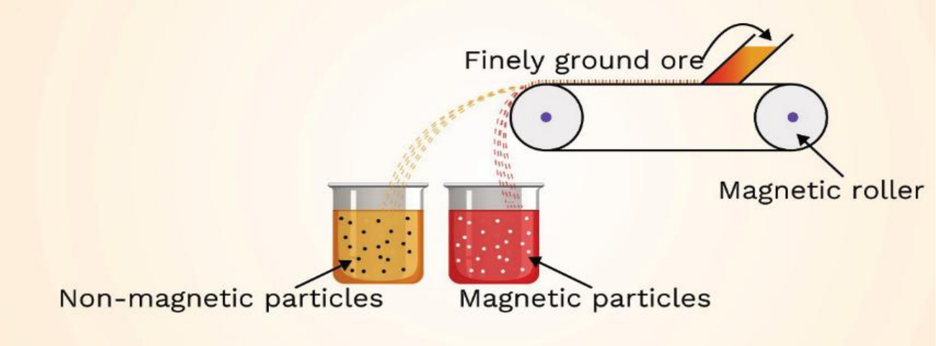


Figure 10 Figure Shows magnetic separation of minerals (Allen, 2023)

2.2.2 Gravity Separation

Enhanced gravity separator (EGS) has been applied in the industry to process coal previously deemed too fine for water-based gravity separators. When utilized for coal, these technologies can effectively handle coal sizes of 53 mm or smaller due to their relatively low cost and ease of handling. Factors such as a decrease in particle mass, an increase in specific surface area, and heightened surface energy per unit area make coal fines and ultra-fines challenging to treat using traditional gravity separation methods because the gravitational force has a minimal effect on ultra-fine particles. To address this issue, enhanced acceleration is employed to effectively separate clean fine coal from the gangue (Ramudzwagi et al., 2020).

2.2.3 Dense Medium Separation (DM)

Particles of varying densities are put into a medium with a predetermined density in a process called dense-medium (DM) separation, often referred to as heavy-medium separation (HMS). While heavier particles sink, lighter ones float. When minerals are placed in a fluid medium with a density of x, those with a density of (+) x sink, while those with a density of (-1) x float. This is achieved at the laboratory scale by using heavy liquids with an appropriate density (Fig 12). To create commercially graded final products, the same procedure is also used in the preparation of coal. The heavier shale or high-ash coal is separated from the clean coal. Rather than using costly or hazardous liquids, the dense medium employed in industrial separations is composed of a heavy solid (such as magnetite) in water (Kumar & Kumar, 2018). The raw coal is separated into various density fractions by using liquids with different densities in a straightforward float-sink test. Particles with densities smaller than the liquid will float in a heavy liquid (dense medium), while particles with densities greater than the liquid will sink. The same idea underlies the dense-media separation method used in commerce. Because low-ash coal particles have a specific gravity of approximately 1–2 g/cm3, while high-ash coal particles have a specific gravity of approximately 2g/cm3, the liquids in this density range offer adequate conditions for heavy-medium coal separation indicate fig 11 (Laskowski, 1989)

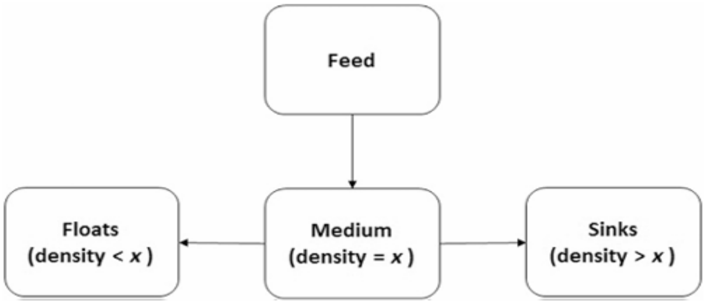


Figure 11 Principle of heavy medium separation (Ramudzwagi et al., 2020)

2.2.4 Jigging

Jigging is a particle stratification technique where a bed of particles alternately expands and contracts due to pulsing fluid flow, causing the particle rearranging. Fluid movement occasionally reverses its vertical direction. The process of jigging produces layers of particles that are stacked from the top of the bed to the bottom according to increasing density.

Stratification of the particles is caused by pulsating water currents, which include both upward and downward currents (Laskowski, 1989).Particles with different compositions (such as non-beneficiated ores) are feed and dispersed across the screen, which is angled slightly in the direction of the outflow end (see Figure 12). Particles undergo many cycles of expansion and compaction as they move through the apparatus, which encourages the stratification activity. The particle bed must be divided into two separate zones upon reaching the discharge end: These are dense particles concentrated in the lower fraction and a layer of light material placed in the upper section of the bed. The height at which the stratified bed should be split at the discharge end is known as the "cut point" or "cut height," and it will be determined by the target content and yield of the intended product shown fig 12 (Ambrós, 2020).

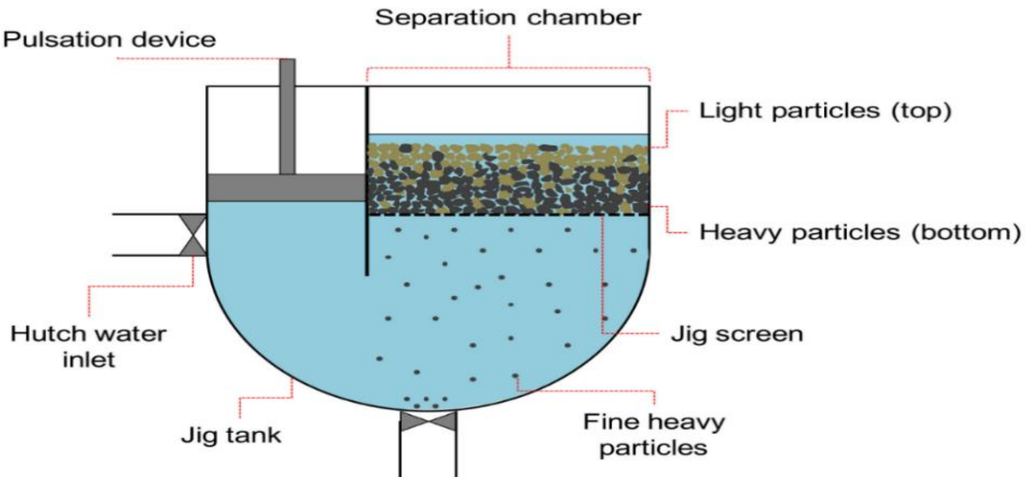


Figure 12 General scheme of a jig (front view) (Ramudzwagi et al., 2020)

2.2.5 Flotation

Froth flotation is a very versatile method of particle separation. Particles with associated air bubbles are transported to the surface and removed, whereas completely wet particles stay in the liquid phase. Foam flotation can be utilized for a wide range of mineral separations because some mineral surfaces can be selectively altered by chemical treatments to give them the characteristics needed for the separation. The separation of sulfide minerals from silica gangue (and other sulfide minerals), the separation of potassium chloride (sylvite) from sodium chloride (halite), the removal of silicate minerals from iron ores, the separation of phosphate minerals from silicates, the separation of coal from ash-forming minerals, and even non-mineral uses like de-inking recycled newsprint are one of its many current applications. In particular, it is useful for treating fine-grained ores that are not suitable for conventional gravity concentration (Fuerstenau & Urbina, 2018).

The two main ways that particles move from the pulp into the concentrate are as follows: The attachment of bubbles to particles with hydrophobic surfaces is the first mechanism. The second is particle entrainment, which impacts all particles but is comparatively more significant for fine and hydrophilic matter. In order for bubble-particle attachment to occur, a stable bubble-particle aggregate must first form and then use buoyancy to migrate to the froth or pulp interface. Once there, the crowding force from more aggregates migrating upward to the froth/pulp interface causes the bubble-particle aggregate to move up into the froth. Bubble-particle aggregates that travel up into the froth and carry the pulp in the top levels of the flotation cell with them cause entrainment. The two main ways that particles can be returned to the pulp after being carried into the froth is (I) Particle drainage, bubble coalescence, and particle detachment. Particles retrieved through bubble-particle attachment are impacted.(ii) The entrainment-recovered particles are impacted by the entrained particles draining from the froth (*AN ANALYSIS OF THE THEORY AND INDUSTRIAL PRACTICE OF FLOTATION : SOME ASPECTS OF THE THEORY*, 1995).

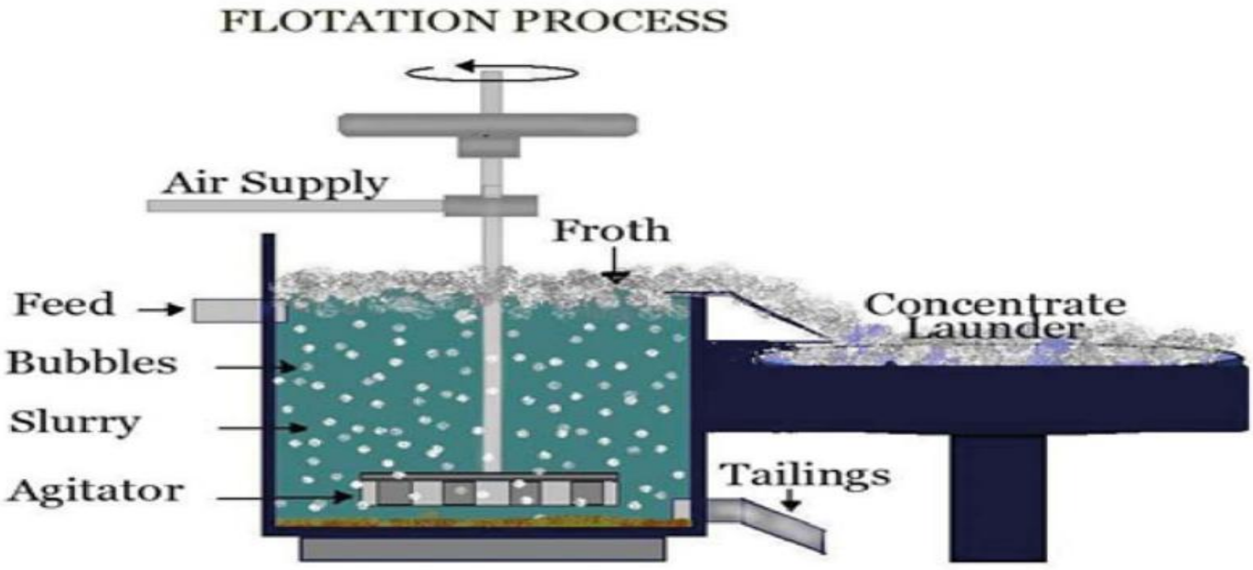


Figure 13 Shows froth flotation process diagram (https://www.ganpatiwires.com/blog/wp-content/uploads/2018/08/Copper-extraction.jpg)

2.3 Coal definition and basic concept

Coal is a black or dark brown, organic and combustible sedimentary rock, characterized by high carbon content and a wide range of physical, chemical, and technological properties. Unlike most other rocks, coal is predominantly made up of organic material, primarily sourced from a multitude of plant sources such as trees, ferns, fungi, and algae, as well as various plant tissues like leaves, stems, wood, bark, pollen, spores, sclerotia, resins, and so on. The mineral content in coal leads to an ash yield (as per ISO 11760, 2005) of less than or equal to 50% on a dry weight basis(Suarez-Ruiz et al., 2018). With 64% of the world's available fossil fuels, coal remains the most significant and prevalent fossil fuel, followed by oil (19%) and natural gas (17%) [9]. Coal is generally categorized as hard and low-rank coal depending on its quality and use. When looking at the ratio of coal varieties in relation to their global reserves, low-rank coal includes lignite (17%) and subbituminous (30%). Hard coal is comprised of bituminous coal (52%) and anthracite coal (1%). The following figure provides the best description of this classification (Flotation, 2023).

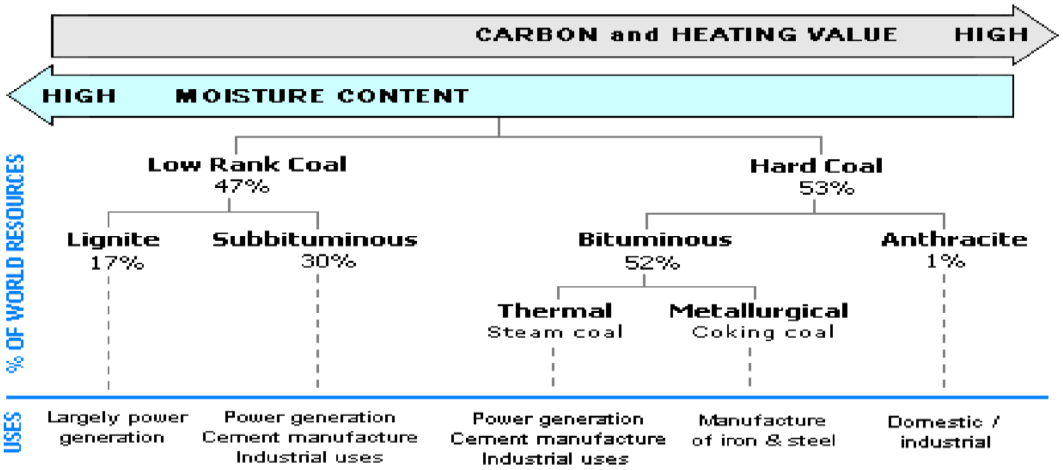


Figure 14 Coal classification, world reserve, and use (Bhattacharya & Dey, 2008).

Although Ethiopian coal reserves are abundant, its quality falls into the lignite to subbituminous category, which is characterized by poor heating value, high moisture content (up to 35%), high volatile matter, low to medium sulfur concentration (1.5 to 3%), and greater ash content (up to 50%) (Flotation, 2023).

2.3.1 Formation of Coal

Initially, plant waste accumulated in a bog-like environment, eventually hardening into a squishy substance called peat. Among these processes were those that led to physical and chemical modifications due to the effects of sedimentary compression and rising temperatures as a result of burial depths reaching several kilometers and enduring over a time span of 100 million years. Eventually, these modifications caused the peat to undergo a process known as coalification, which turned it into coal (shown in Figure 15). A biochemical phase, which follows the deposition of organic waste and takes place at shallow levels in the peat bog, precedes the coalification process. A geochemical phase or coal transformation comes next. The most significant and permanent physical and chemical transformation occurs during this second stage, which progresses from the lignite stage to sub-bituminous, bituminous, anthracite, meta-anthracite, and finally, graphite, the last stage of organic development (though not always in its purest form).Long-term subject to heat and pressure causes coal to undergo metamorphosis shown fig 14 (Norori-McCormac et al., 2017)

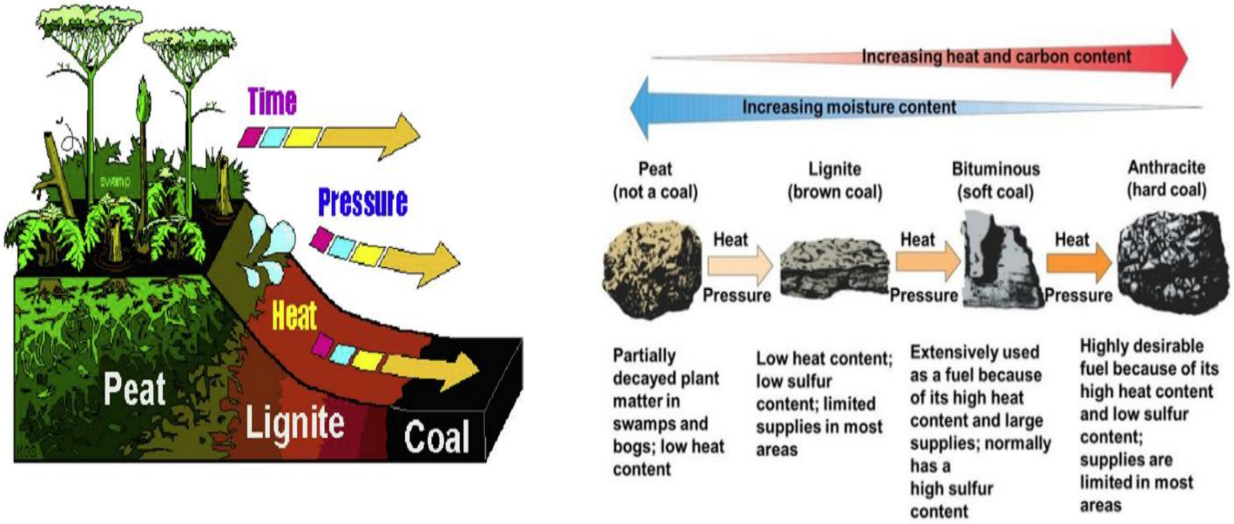


Figure 15 Shows the process of coal formation (Di Gianfrancesco, 2017, Iastoppers, 2024)

Temperature is generally regarded as the most important component. It's generally accepted that time contributes to coalification as well, with the period needed to attain various coal ranks ranging from under a year in contact transformation to an impressive 106 to 107 years for regional metamorphism. The function of pressure has been a topic of debate for quite some time, and while it's been established that pressure promotes physical-structural coalification, which impacts the physical qualities of coals. The extent of coal transformation, commonly known as the coal rank, signifies the stage of metamorphosis in coal (coalification). This phase involves a continual reduction in moisture and volatile chemical components, accompanied by an increase in the carbon concentration within the coal (as depicted in figure 14 below). Consequently, coal rank serves as a distinguishing feature that categorizes various classes of coal (Suarez-Ruiz et al., 2018).

2.3.2 Coal Composition and Mineralogy

Coal is a heterogeneous material made up of various amounts of various organic components known as macerals. In the same way that minerals make up rocks, minerals also make up coal. The difference is that, unlike macerals, minerals maintain their chemical and physical characteristics irrespective of their size. In geological point of view, the constituents of coal are categorized according to their maceral type, a microscopically assessed classification. From a petrographic perspective, coal can be broadly defined as a mixture of mineral and plant matter (Groppo, 2017).

Coalification is the process by which accumulated plant matter becomes humified and eventually coalifies. By weight, C makes up the majority of the elements in the organic matrix, with minor amounts of H, O, N, and S as well as several trace elements (Tishmack & Burns, 2004). Clay minerals are the most prevalent in coal, with kaolinite, illite, montmorillonite, and smectite being the most common. Following these, carbonates are the next most prevalent minerals, which include dolomite, calcite, and siderite. Additionally, coal contains silicates, such as quartz and zircon; oxides like rutile; and sulfides including pyrite, sphalerite, and galena. Some of these minerals can be found in significant concentrations locally as shown in the table 2 below (Mastalerz et al., 2010)

Table 1 Mineral constituents in coal (Tishmack & Burns, 2004)

Mineral	Chemical formula	Trace element associations
Silicates • Kaolinite • Illite • Mixed Illite-Smectite • Chlorite • Quartz • Feldspar	$A1_2Si_2o_5(OH)_4$ $KA1_2(AISi_3O_{10})\ (OH)_2$ $A1_2Si_4O_{10}(OH)_2.H20$ $Mg_5AI(AISi_3O_{10})\ (OH$ $SiO2$ $(K, Na)\ A1Si_30_8$	Lithophile elements: Li, F, B, Cr, Sr, Ba, I, Ti Br, Mn
Oxides • Hematite • Magnetite • Rutile • Anatase	Fe_20_3 Fe_3O_4 TiO_2 TiO_2	Siderophile elements Ni, Co, Mo, Mn, P, Ge, Pt, Ti, Sn
Sulphides • Pyrite • Marcasite • Pyrrhotite	FeS_2 FeS_2 $Fe1-xS$	Chalcophile elements: As, Cu, Co, Pb, Hg, Zn Mo, Cd, Se
Sulphates • Gypsum • Jarosite • Thenardite	$CaSO4.2H20$ $KFe3(SO4)2(OH)_6\ Na_2SO_4$	Na, Sr, Ba, Pb
Carbonates • Calcite • Dolomite • Siderite • Ankerite	$CaCO3$ $CaMg\ (CO3)_2$ $FeCO_3$ $Ca\ (Mg, Fe, Mn)\ (CO)_2$	Mn, Zn, Sr
Chlorides • Sylvine • Halite	$KC1$ $NaC1$	-

The concentration of these minerals varies according to the depositional environment. The amount and composition of these minerals play a crucial role in the chemistry of fly ash, as these inorganic components are non-combustible and influence the chemical properties of the residual ash following the combustion of the parent coal. Coals that contain higher levels of sulfide minerals, such as pyrite and marcasite, will naturally yield ash with increased iron concentrations. The minerals most frequently encountered in coals belong to the shale and kaolin groups, which possess significant elemental concentrations of aluminum and silicon (Groppo, 2017).

2.4 Classification of Coal

Various coal classification systems have been suggested by various authors since the latter half of the 19th century. The majority of these systems rely on the physical, chemical, and technical characteristics of the coals.

2.5 Physical Properties

Based on their fundamental characteristics, coals can be divided into two primary groups: Humic and sapropelic. Humic coals display a banded structure and are predominantly composed of minute plant remnants, observed under a microscope. These coals are further categorized into four subtypes, known as lithotypes. These lithotypes are distinguishable by their macroscopic bands in coal, such as Vitrain, Clarain, Durain, and Fusain. Sapropelic coals are typically non-layered, primarily consisting of microscopic plant debris, spores, pollens, algae, and typically exhibiting a conchoidal break. These coals can be categorized into cannel coal, boghead coal, and the intermediate type between the two, known as cannel-boghead coal and boghead-channel coal (Akbari, 2009).

The Humic and sapropelic coals contaminated with clay minerals, mica, and quartz, classified as carbonaceous shale, are a common occurrence. These coal variants are distinguished by their dark hue, lackluster appearance, hardness, and compact structure, making them denser than regular coal. In many instances, composed primarily of carboargillite (containing 20-60% by volume of clay minerals, mica, and quartz), may also contain carbosilicate and carbopyrite (Akbari, 2009).

2.6 Chemical Parameters

Coals are classified into four categories by analyzing their chemical properties: peat, lignite, bituminous, and anthracite. This categorization is primarily determined by the levels of carbon, ash, and moisture.

2.6.1 Peat

Peat is not the same as coal and is instead the initial stage of transformation, derived from the accumulation of partially decomposed vegetation or organic matter in natural environments. This process occurs in exceptional ecosystems known as peatlands which act as the most powerful carbon sink on Earth. The reason for this is that peatland plants absorb the CO2 naturally released from the peat, thereby maintaining equilibrium. Sphagnum moss, commonly known as peat moss, is a significant component in peat, although various other plants also contribute to its development. Peat is formed in wetland conditions, where a lack of oxygen flow from the atmosphere due to flooding or stagnant water slows down decomposition. According to Breeze in 2015, peat comprises less than 40-55% carbon, has an adequate quantity of volatile elements, lot of moisture, and impurities (*CLASSIFICATION OF COAL Numerous System of Coal Classification Has Been Proposed by Different Authors since the Later Part of the 19*, 2017).

2.6.2 Lignite

Often referred to as brown coal lignite is a delicate, brownish-toned, burnable sedimentary rock that arises from the natural compression of peat, marking an intermediate stage in the coalification process. This type of coal is often classified as the most fundamental due to its relatively low energy output. Its carbon content amounts to 60-70%, it holds substantial moisture levels reaching up to 75% and its ash content ranges from 6-19%. The high volatile material in lignite results in its spontaneous ignition (Akbari, 2009).

2.6.3 Bituminous

Often referred to as "soft coal" or "black coal," this type of coal is easily accessible. It has less moisture and volatiles than lignite coals, and it has a significant amount of carbon (between 69% and 86%). The moisture and volatile content of bituminous coals can vary from 5% to 45% making it highly combustible when reduced to powder due to its high energy content and volatile nature. This results in a prolonged and intense flame during combustion. These coals are characterized by their density and compactness, boasting an extremely high energy yield. They are mainly employed in the production of coke and gas. From a geological standpoint, bituminous coals can be traced back to the Carboniferous to Cretaceous periods and have a wide geographical distribution worldwide (*CLASSIFICATION OF COAL Numerous System of Coal Classification Has Been Proposed by Different Authors since the Later Part of the 19*, 2017).

2.6.4 Anthracite

Anthracite is a type of coal that undergoes the most extensive metamorphosis, resulting in a coal of the highest quality. This particular coal is characterized by its shiny black color, hardness, and brittleness, and it boasts exceptionally high fixed-carbon content, ranging from about 86% to 98%. The low volatile matter content in anthracite (between2%and12%) leads to aslow combustion process. Anthracite burns with a hot, clear blue flame, emitting minimal sulfur and volatile compounds. Due to its unique properties, anthracite is sometimes used in domestic applications or in industrial applications that call for smokeless fuels shown fig 16 (Akbari, 2009).

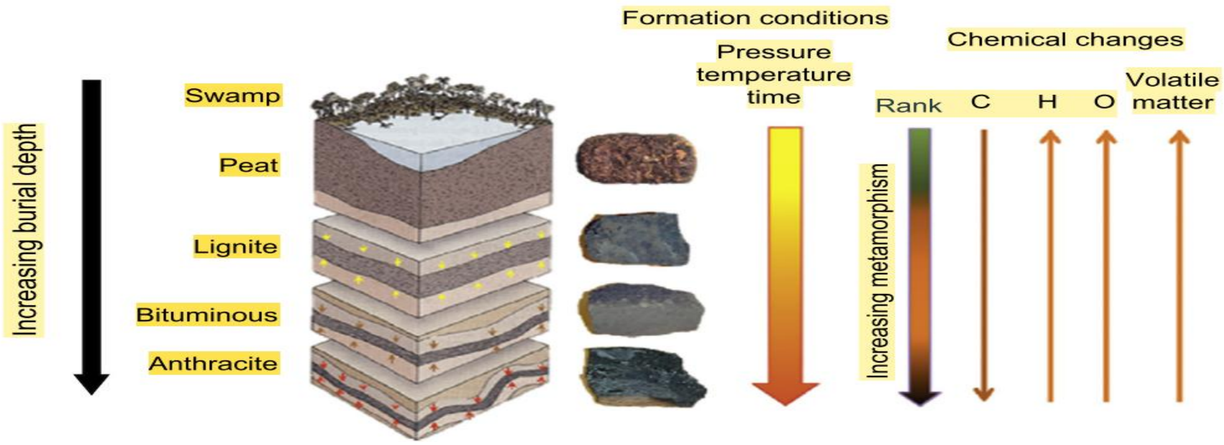


Figure 16 Scheme of the formation of coal in terms of rank (coalification series) (Suarez-Ruiz et al., 2018)

As geological processes put pressure on dead biotic material over time under favorable conditions, the degree or order of metamorphism successively increases as shown figure 18 Coal originated from ancient vegetation that thrived in swampy conditions millions of years ago. The abundance of water limited oxygen availability, facilitating the thermal and bacterial breakdown of plant matter rather than allowing the carbon cycle to proceed to completion. This anaerobic decomposition process, known as the biochemical stage of coal formation, resulted in the creation of a carbon-dense substance referred to as peat. Following this, the geochemical stage involved varying time-temperature conditions, which ultimately produced coals with diverse characteristics, as outlined in the table 3 (Zhu, 2010).

Table 2 Carbon content and age of different coals (Zhu, 2010)

Coal type	Approximate age(years)	Approximate carbon content, %
Lignities	60,000,000	65-72
Subbituminous coal	100,000,000	72-76
Bituminous coal	300,000,000	76-90
Anthracites	350,000,000	90-95

2.7 Application of coal

2.7.1 Coal Uses for Power Generation Industry

The largest first usage of coal is the power generation sector. A plant built for one type of coal might not be appropriate for other types, however modern coal-based combustion systems can employ a wide range of coals depending on the system design. A significant and established energy source in the United States, Canada, and Australia, coal-fired power generation is currently expanding quickly in China and India. According to a recent assessment by the Coal Industry Advisory Board (CIAB report, 2011) the world will continue to rely on coal use for many decades to come. It is anticipated that between 2006 and 2030, the use of coal will increase by more than 60%, with 97% of this growth occurring in developing nations. However, more than 40% of all CO2 emissions related to energy come from coal, making it the most carbon-intensive fossil fuel. The same report outlined the steps that must be taken to allow coal use to successfully meet CO2 reduction goals (Osborne & Gupta, 2013).

2.7.2 Coal Uses for Cement Industry

The growth of the modern world has been greatly aided by coal-based industries, which are predicted to continue to dominate for a very long time, especially in developing nations. Coal is the most prevalent and extensively dispersed fossil fuel in the world, accounting for 64% of worldwide recoverable fossil resources, while oil and natural gas make up 19% and 17% of global fossil fuels, respectively. The two main markets for coal are metallurgical coal (mainly for steel making) and thermal coal (for energy use, including power generation and other applications like the cement manufacturing sector), though there are other uses for coal as well, such as conversion into gas or other energy or chemical products, and in situ forms, wherein native coal deposits are gasified and the gases are used after some treatment. Nearly 70% of the world's steel industry utilizes coal for either coke production or coal injection, either as the energy/reductant source in direct reduction operations or through the so-called integrated method. Around over 25% of the world's basic energy demands can be supplied by coal, with thermal coal accounting for around 40% of global electricity production (Osborne & Gupta, 2013).

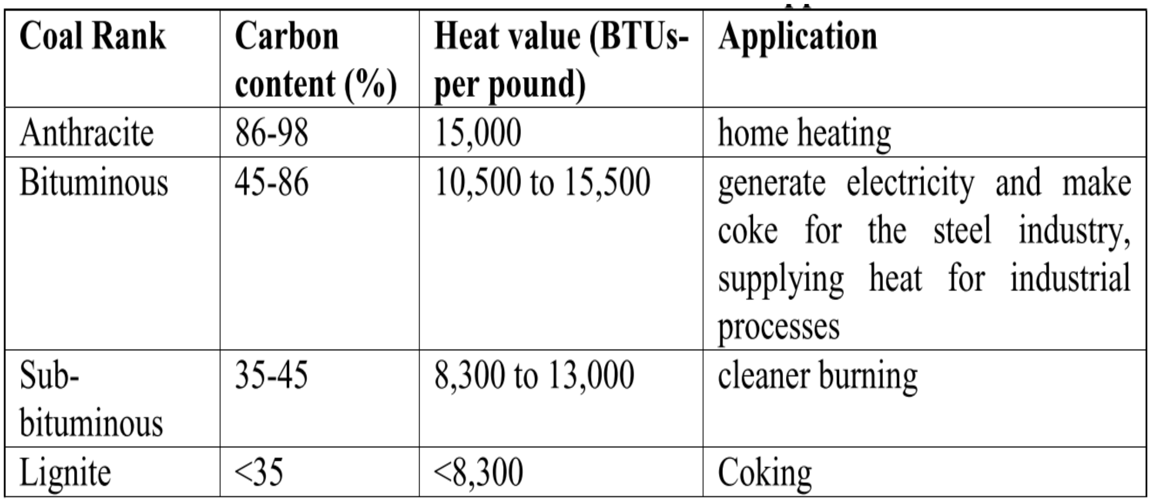
The production of cement requires a lot of energy. For every ton of cement produced, kilns typically burn coal in the form of powder, such as ~70% < 75 microns, and use about 450 g of bituminous coal, though ash contents can vary greatly, ranging from as low as 5% (rare) to roughly 20% for imported coals, but higher (up to 30%) for some local sources. Determining the ash's possible contribution to the final mix also depend on its constituents. Therefore, coal plays a part in the following processes that result in the production of cement and concrete (Osborne & Gupta, 2013):

- Bottom ash and fly ash from coal-derived power plants are commonly used as constituent raw materials.
- In rotary kilns, pulverized coal is used as fuel.
- When the qualities of coal-derived fly ash are favorable, it is added to concrete mixtures as a substitute for Portland cement.
- Fuel ash from coal is added to a clinker mix to increase the value of blended cements.
- Certain ash products, like ash containing cenospheres (small diameter slag bubbles), are used to make lightweight aggregates for construction materials.

For making steel: In order to smelt iron ore into the iron required to make steel, coal is baked in hot furnaces to create coke. The extremely high temperatures produced by using coke are what give steel its strength and flexibility for items like buildings, bridges, and automobiles. Coal is essential for the production of iron and steel (70% of steel is produced in blast furnaces using coal and coke) (Demoze, 2007).

Direct application of coal: After being processed into coal briquettes, coal can be used as a source of energy for small businesses and households (for cooking and heating in the home and for heating in industrial processes). In industries, coal can be a significant alternative energy source. In addition to electricity, petroleum products are used as a potential energy source by many industries. For instance, the cement, metal, and other industries in Ethiopia invest a significant portion of their capital in fuel purchases, and they may be the primary consumers of the product among other industries shown in table 4 (Demoze, 2007).

Table 3 General Coal ranks with their application (Kebede et al., 2019)



Coal Rank	Carbon content (%)	Heat value (BTUs-per pound)	Application
Anthracite	86-98	15,000	home heating
Bituminous	45-86	10,500 to 15,500	generate electricity and make coke for the steel industry, supplying heat for industrial processes
Sub-bituminous	35-45	8,300 to 13,000	cleaner burning
Lignite	<35	<8,300	Coking

2.7.3 Coal Deposit in Ethiopia

Coal deposits in Ethiopia can be divided into two geological types of sources these are inter-trap volcanic and pre-trap volcanic. Sandstone–coal–shale facies (I) and siltstone or mudstone–coal–shale facies (ii) make up this group. The sandstone–coal shale facies host larger and more durable coal seams than the siltstone or mudstone–coal shale facies. There are substantial coal reserves in the Delbi-Moye, Chilga, Yayu, Lalo-Sapo, Nejo, Wuchale, and Mush Valley Basins. (Fig. 20) (Wolela, 2007).

2.7.4 Gojeb-Chida Basin

The basin is located in latitude 7°10′–7°19′N and longitude 36°45′–36°53′E. The basin is composed of both volcanic and sedimentary rocks. The evolution of the basin is connected to the NNW–SSE trending fault system. The majority of the coal-bearing layers in the Flavio-lacustrine are composed of territorial and organogenic sediments. The sediment is unconformable over the 30.45 Ma lower basalt, and the 10.98 Ma upper basalt sits on top of it. The maximum thicknesses of coal seams and coal-bearing sediments are 2.5 and 60 meters, respectively. The sediments that contain coal cover around 4 km². The Gojeb-Chida Basin is thought to contain a 9.5 Mt lignite to subbituminous coal deposit. The coal-bearing layers were confirmed to be Eocene to Miocene by paleontological studies of pollen and spores (Wolela, 2007) .

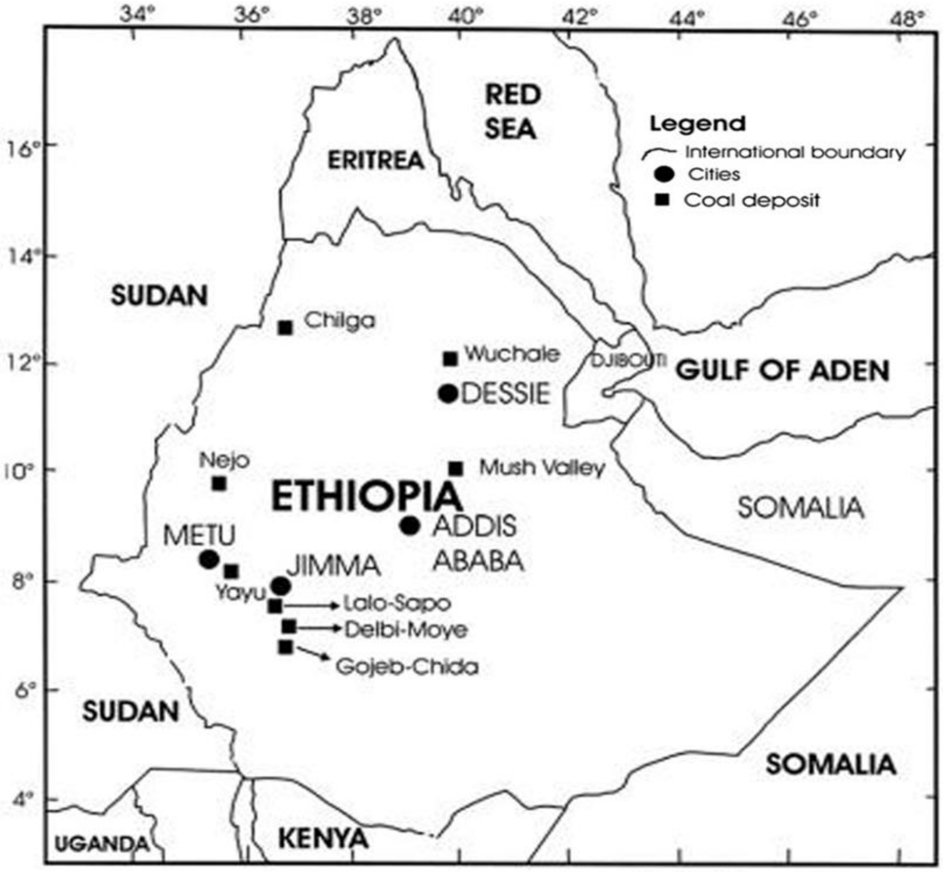


Figure 17 Location map of coal deposits of Ethiopia (Wolela, 2007)

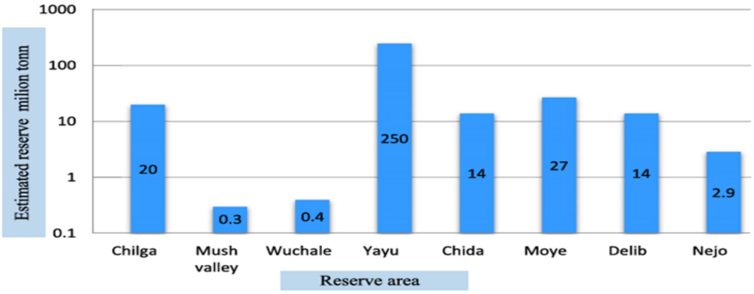


Figure 18 Shows estimated coal reserved areas in Ethiopia (Genetu & Kebede, 2024)

CHAPTER THREE

3 Methodology

3.1.1 Instruments and Apparatus

Instruments and equipment utilized in the batch flotation experiment are: jaw crusher machine (RoHs53743 fig a) centrifugal miller (RETCH-56402 fig b) sieve- shaker (RETCH-A200 fig c), batch flotation cell, (Groppel-98 fig d) Universal Hot-oven, Silica -crucible, Furnace (XMT-F9) and electronic balance (AUW-320Philippines) at Addis Abeba institute of technology, adiabatic boom calorimeter (fig e), Aluminums foil, pH meter.

a) b) c) d) e)

Figure 19 Shows instruments and apparatus used in the lab

3.1.2 Chemical Reagents

The chemical reagents used in the study included sodium silicate (Na_2SiO_3) as a depressant, sodium carbonate (Na_2CO_3) as a pH regulator, n-octanol ($CH3(CH2)7OH$) as a frother, and kerosene as a collector.

Figure 20 Shows reagents used in the flotation experiment n-octanol ($CH3(CH2)7OH$), kerosene and sodium silicate (Na_2SiO_3) respectively.

3.1.3 Coal Preparation

When coal is extracted, it includes some rock separations along with inorganic elements known as mineral matter. Therefore, coal must undergo a cleaning process to decrease the mineral matter before it can be utilized for burning. This process is carried out in a coal processing facility located at the mine site. This step in coal mining is known as coal preparation (Holuszko &deKlerk,2013).

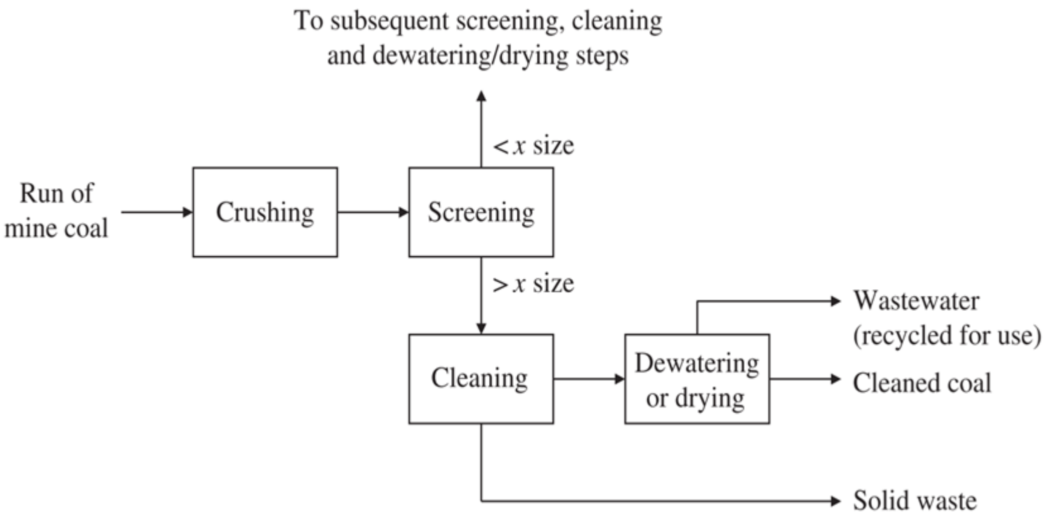


Figure 21 Coal preparations, a basic physical coal cleaning process (Holuszko & de Klerk, 2013).

In order to reduce moisture in the final product and remove the majority of non-combustibles (mineral matter), coal preparation or processing is required to improve transportation economics. Improving the homogeneity of the coal delivered to the final user is another goal of efficient coal preparation. Removing non-combustibles from coal used to generate electricity improves process efficiency and reduces the amount of ash that needs to be disposed of at the power plant. By removing coal's Sulphur-bearing minerals, it also lowers SO2 emissions (Holuszko & de Klerk, 2013).

The coal purification process involves a physical cleaning phase (as shown in Figure 21). Initially, the coal is crushed to facilitate the separation of mineral components from organic matter. Afterward, the crushed coal is screened to categorize it into various size fractions. The type of screen employed depends on the size of the coal being treated. The coal cleansing takes place separately for coarse, intermediate, and fine coal, as each requires distinct handling methods. Excessive size reduction should be avoided, as finer coal particles can be challenging to handle, dewater, and clean. The mineral waste generated during this separation process serves as a solid by product. The separation between mineral and organic components is not total. Some mineral particles remain attached to the purified coal, while some organic matter is discarded alongside the solid waste (Holuszko & de Klerk, 2013). Due to the significant differences in the composition and characteristics of coals, it is essential to have a classification system that describes the various types suitable for residential and power generation applications (*AN ANALYSIS OF THE THEORY AND INDUSTRIAL PRACTICE OF FLOTATION : SOME ASPECTS OF THE THEORY*, 1995)

3.1.3 Method of The Study

The primary data was sourced from batch flotation laboratory work observation while secondary data was obtained from published and unpublished documents, journals, books, previous reports in ministry mines, Websites, previous reports in mining site and through interview with mining engineer at Kiripto mining and chemicals plc. A typical coal sample was used for the study from Kripto Coal Mining and Chemicals Plc, a coal preparation company in the south-western Ethiopian region of Konta Zone Elasanchano Wereda Chida.

The company uses an open pit mine technique that is 20–30 meters below ground level. The collected sample is blended coal which is formed by mixing of different calorific value of coal that found from different layers or depth with the same area or mined site. Blending coal that found from different layer or depth of coal is the common practice in coal processing industry. To achieving specific quality attributes required for various applications such as power generation. the company mix the lower calorific value with the higher calorific value to get the mean or average of the whole to become approach to the standard and Consistent. The production of blended coal is depending on the customers demand standard. Generally, it depends on the standard of the plant which it requires and type of industry which it use. The method of data collection was both primary and secondary method of data collection. The complete set of experimental methods used in the study and coal sample data analysis were summarized in the figure below. The experimental procedure includes, sample preparation, coal flotation experiment, proximate, ultimate analysis of coal, determination of calorific value and quantify the grade and recovery of the blended coal (Figure 22).

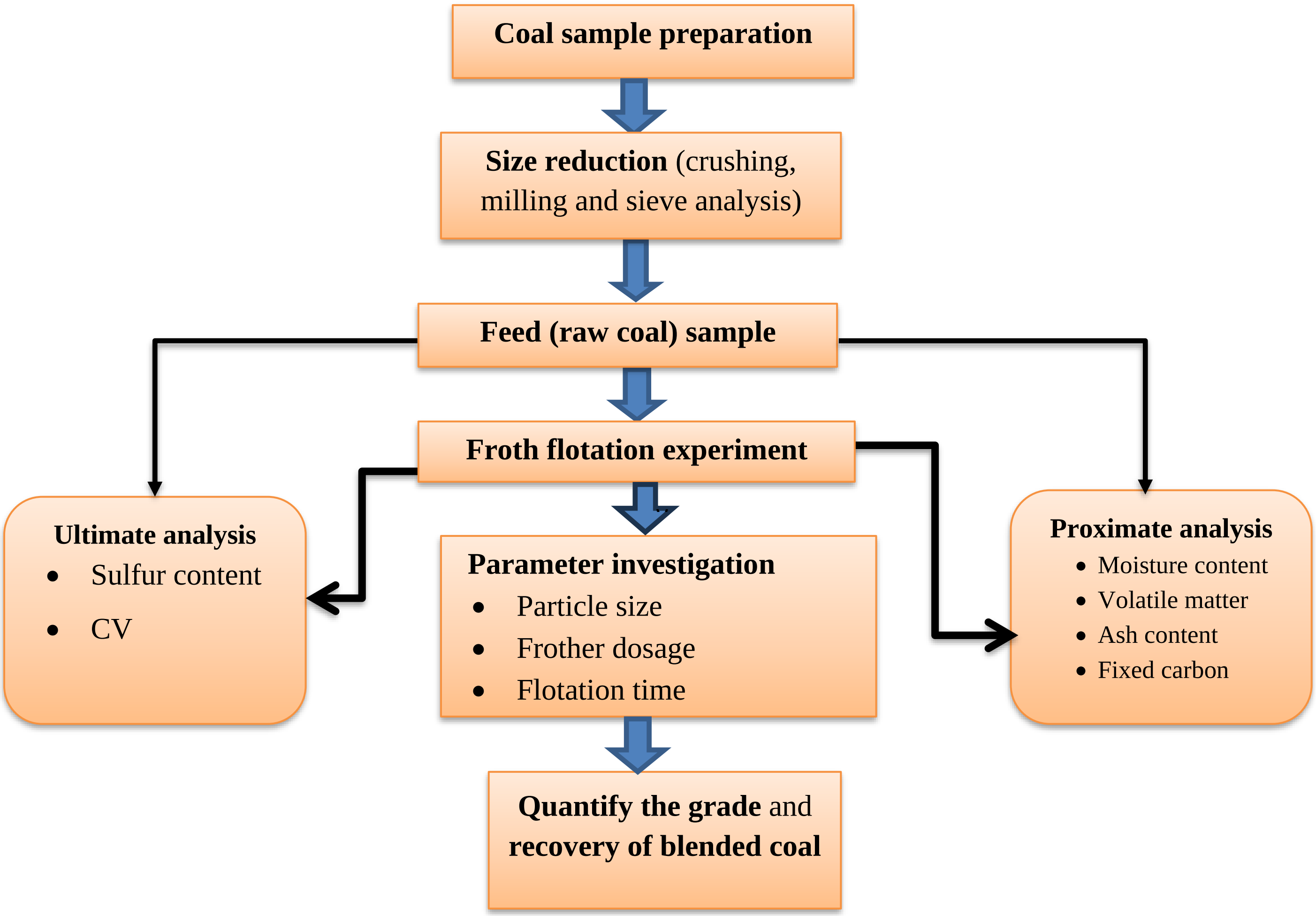


Figure 22 Shows experimental design of blended coal flotation

3.1.4 Coal Sample Preparation

The coal sample was collected from Kiripto coal mining and chemicals plc konta zone Elsanchano wereda Chida south west region of Ethiopia. This area is one of low-grade coal potential deposit in the country. The coal sample was prepared according to ASTM D-2013 standards. The coal sample was dried in 24hours for the removal of extraneous moisture from the sample and ready for size reduction by jaw crusher, centrifugal miler in order to get the required particle size.

First the coal sample was crushed by jaw crusher to reduce the particle size 1-2mm next centrifugal miller was used to get the fine powder product approximately under 500mm. then the milled product was taken in to the sieve shaker to separate the coarse particle from the fine product. The sieve shaker was arranged from higher to lower 500 µm,250 µm, 125 µm, 63 µm. Finally., the powder coal sample was separated in three particle size range -250+500 µm, +125+-250 µm, +63+-125 µm and ready for the flotation experiment.

Table 4 Shows the amount of prepared sample after sieving ready for flotation experiment

S/N	**Particle size in (µm)**	**Amount of coal sample prepared after sieving in (gram)**	**Sieving time(minute)**
1	+63+-125	394	7
2	+125+-250	2,049	7
3	+250+-500	2,261	7

3.1.5 Experimental Procedure

The batch flotation cell experiment was carried out using the following procedures with variation of three operational parameters (particle size, frother dosage, flotation period).

Step1.preparation of coal sample: 5 kilograms of the blended coal sample were measured by analytical balance. The measured coal sample was put into the jaw crusher to reduce the particle size. Next centrifugal miller was used to grind the crushed coal get the fine powder product approximately under 500mm.Then the milled powder product is taken into the sieve shaker to separate the particles in different sizes. The sieve shaker was arranged from higher to lower +500 µm, +250 µm, +125 µm, +63 µm.

Step2. Preparation for flotation: The fine particle size of 63, 125,250 µm were prepared for flotation and the capacity of flotation cell was 3Lwere used. Thus 2 litter of tape water were added to the flotation tank and then 100grams of each particle size coal sample were added to the flotation cell in the order of 63 µm, 125 µm, 250 µm respectively with 6.4 PH value and 1.5ml of sodium silicate added as depressant after this the experiments were conducted separately with three replications for each particle size. To see the effects of different particle size then the mixture was agitated for 2minute and 10minute flotation time with stirring speed of 1850r/pm until the particles were wetted fully with constant other variables.

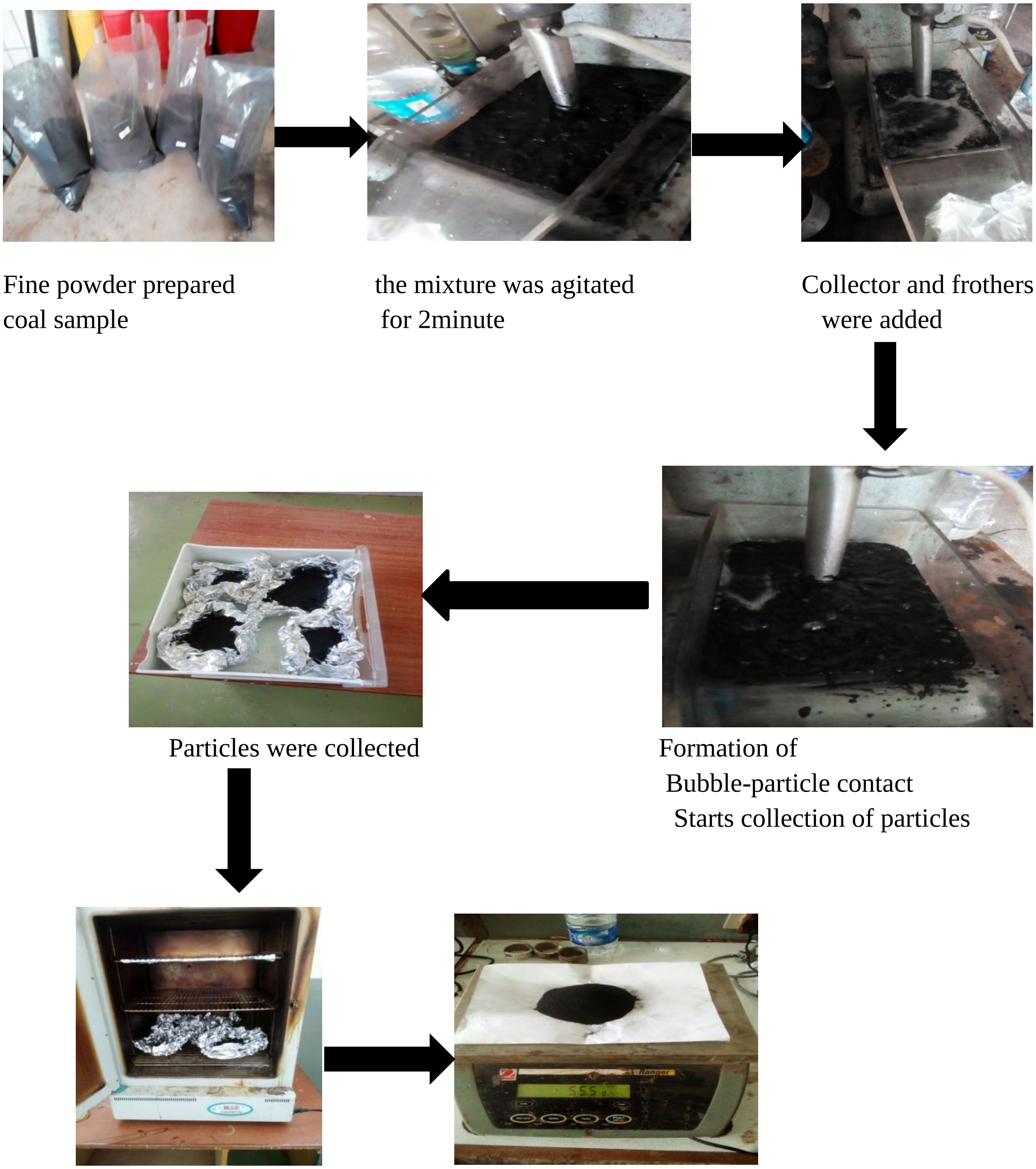
Step3.Addition of reagent: A next 10ml of kerosene (collector) was added with a constant dosage to know the impact of particle size and agitated for 2minute while the air valve was closed. Then 3ml of n-octanol (frother) added while the air value is opened to supply the air in the floatation in order to make the required bubble particle contacts in the flotation cell. After observing the effect of particle size vary the frother dosage(3ml,6ml,9ml) and conduct the experiment with constant other variables to observe the effect of frother dosage in the same procedure. Finally repeated the procedure with vary flotation time of 5, 10, 15 minute and observe the impact.

Step4. Bubble formation and collection of products: 0.5L of litter water is added to the flotation cell across for all flotation parameters after bubble formation has started. The bubble that developed then began to overflow, and the flow particles were collected as a byproduct. Continue collecting the foam that forms until white foam is seen, a sign that every solid particle in the cell is connected to the oil collectors (Turap et al., 2015).

Step5. Final processing of collecting particles: The collected and skimmed particles were filtered, followed by drying in a hot oven at 105°C and the yield of the concentrate is calculated from the recorded data from each parameter flotation experiment by the equation given below (Melo & Laskowski, 2005).

$$Yield\% = \frac{MC}{\mathrm{MF}} X100\%$$

Where Mc weight of flotation concentrate, and Mf is weight of feed coal sample in grams



Fine powder prepared coal sample

the mixture was agitated for 2minute

Collector and frothers were added

Formation of Bubble-particle contact Starts collection of particles

Particles were collected

The collected sample was dried In the oven at 105°C

final collected concentrate coal sample

Figure 23 Shows flotation flow diagram process

3.2 Proximate analysis of coal

Coal is analyzed proximally by measuring its moisture content, volatile matter, ash content, and fixed carbon content.

3.2.1 Determination of Moisture Content

The mass lost when a sample dry is called moisture, and it is expressed as a percentage. When water replaces combustible materials in coal, the heat content per kilogram will fall(Mdoe & Anupam, 2021). Total moisture was determined in accordance with ASTM D-3302 standards, which involved placing 1 grams of air-dried fine coal sample in a silica crucible and slowly heating it for three hours at an experimental temperature of 107 °C. After being removed from the hot oven and allowed to cool in a dissecator, the heated sample was weighed again and its moisture content was determined using (Turap et al., 2015).

$$\text{moisture}(\%) = \frac{\text{weight of sample after dry (g)}}{\text{weight of sample before dry (g)}}\, x100$$

3.2.2 Volatile Matter Determination

According to ASTM D-3175 testing procedure, 1g of air-dried sample was weighed in a silica crucible covered with a lid to prevent sample oxidation in order to calculate the percentage of volatile matter. Next, in a muffle furnace without air, the sample was precisely heated to 950±5°C for seven minutes. Following heating and placing in a dissecator to cool, the sample was weighed once more, and the volatile matter was calculated using (Turap et al., 2015).

$$volatile\ matter(\%) = \frac{\text{loss in weight}}{\text{weight of sample taken}} x100\% - moisture\%$$

3.2.3 Ash Content Determination

Based on ASTM D-3174 standard procedure, the amount of ash was calculated. A crucible made of silica was filled with 1g of the sample, which was then heated for three hours without lid covers to a temperature of 850±5°C in a muffle furnace. After the combustible matter was burned, the ash was allowed to cool in a dissecator before being weighed again and the ash content was determined using (Turap et al., 2015).

$$\text{Ash content} = \frac{\text{weight of ash residue after burning (g)}}{\text{weight of sample taken in (g)}}\ x100\%$$

3.2.4 Fixed Carbon Determination

The coal sample's fixed carbon percentage was calculated using ASTM D-388 guidelines. Subtracting the total of moisture matter, volatile matter, and ash content from 100 using was the next step in calculating fixed carbon (Turap et al., 2015).

$$\%\ of\ fixed\ carbon = 100\% - (\%\ \text{moisture} + \%\ \text{ash} + \%\ \text{volatile matter})$$

3.3 Ultimate analysis of coal

This technique which is also referred to as elemental analysis or ultimate analysis measures the amount of carbon, hydrogen, nitrogen, sulfur and oxygen in a coal. Finding the percentage of C and H: A combustion apparatus burns asample of coal that has been precisely weighed. Coal's carbon and hydrogen are transformed, respectively, into carbon dioxide and water vapor. (Of & Seam, n.d.).

3.3.1 Sulphur

The washings off from a known mass sample of coal used in a bomb calorimeter to measure the calorific value are used to determine the sulfur content. This determination results in the conversion of S to sulfate. When the barium sulphate precipitates, the washings are treated with a solution of barium chloride. This precipitate is heated to a consistent mass, filtered, and cleaned (Srinagar, n.d.).

$$\%\ of\ S\ in\ coal = \frac{\text{mass of BaSO4 obtained x32}}{\text{233 x mass of coal sample taken in bomb}} x100$$

Although sulfur increases the heating value of coal, as it burns, it produces acids (SO2) that corrode machinery and pollute the atmosphere.

3.3.2 Oxygen

Oxygen content reduces coal's calorific value (a 1% increase in oxygen content reduces the value by approximately 1.75), making it undesirable. The coal's ability to retain moisture rises with increasing oxygen content, while its heating power falls (Srinagar, n.d.).

It is obtained by difference

$$\% \, oxygen = 100\% - \mathrm{percentage}(\mathrm{C + H + S + N + Ash})$$

3.3.3 Determination of Calorific Value

A nickel crucible was inserted into adiabatic bomb calorimeter that was held up by a ring after a sample of around 1 gram of powdered coal had been precisely weighed. In order to ensure full combustion, oxygen was injected into the adiabatic bomb calorimeter through a valve until the pressure reached 25 to 30 atmospheres. Following that, the bomb was submerged in 2000 milliliters of distilled water in a nickel bucket. The initial temperature was recorded when the power was turned on, and the bomb was lit once the bucket's temperature equaled the bombs. From the reading device, the highest temperature was recorded. To release any remaining gas pressure, the knob valve was then gradually opened once the bomb had been carefully taken out of the bucket before taking off the cap. To calculate the net amount of wire used, all unburned fuse wire segments from the bomb electrode were removed, straightened, and their total length was measured in centimeters. The bomb was then cleaned and titrated using a methyl orange indicator and a conventional sodium carbonate solution. The relevant equation was then used to get the gross heat of combustion (Turap et al., 2015).

$$GCV = \frac{(\mathrm{tW - e1 - e2 - e3}}{m}$$

GCV= Gross calorific value in Btu/lb.

t = the temperature change

W = energy equivalent of calorimeter in cal/^{o}C

e1= correction in calories for the heat of formation of nitric acid (HNO_3)

e2 = correction in calories for the heat of formation of sulfuric acid (H_2SO_4)

e3= correction in calories for the heat of combustion of fuse wire

m = mass of coal sample taken in gm

CHAPTER FOUR

4 Flotation Experimental Results

The coal particles were floated following the addition of kerosene (collector) at the conditioning period (t= 2minute) and the formation of big bubble was seen but the oily bubbles' surface is free of particle (figure 24 a). The bubble was stabilized small in size after addition of n-octanol (frother) at conditioning time (t=2minute) (figure 24 b). The resulting foam particles were collected as a concentrate by aluminum foil until at the end of flotation time and there was white foam, which shows that every solid particle in the cell is connected to the oil collectors. (fig 24 c) after this dried in 105 °C oven(d) and final concentrate coal sample taken for characterization(e) (Turap et al., 2015).

Figure 24 Shows experimental results

The production of blended coal is based on the customers demand and standard of the plant. The study conducted by collecting the blended coal sample from Kripto coal mining and chemicals plc. The company produces blended coal based on the customers demand type of industry it use and deliver to the cement factories. The production of blended coal enables quality enhancement, coast minimization and fulfils the customer demand. The working principle of Kripto coal mining and chemicals PLC is considers the blended Gross Calorific Value of coal is greater or equal to the average or mean value of the coal before blended indicates Effective blending process based on this the raw blended coal sample Gross Calorific Value using calorimeter is 4,914.73ca/gram the average or mean of the GCV of coal before blended is 4,758.675ca/gram this indicating an effective blending process that enhance the quality of the final product. It full fills the minimum requirement the ability to achieve a GCV of not only meets but exceeds the minimum requirement set by customers, thereby ensuring satisfaction and compliance with industry standards.

Table 5 shows the calorific value of coal before blended and after blended

Sample no	Calorific Value before blended in (Ca/gram)	Measured value of raw Blended coal Calorific value	Source of data
1.	4,480.6	4,914.730Ca/gram	Kripto mining and chemicals PLC
2	4,370.1		
3	4,742		
4	5,442		

4.2.2 Determination of Ash Content in Different Particle Size

Coal ash is the residue that is produced when coal is burned in the presence of air. The noncombustible inorganic debris that remains after burning coal includes clay minerals, silt particles of quartz, carbonate, iron oxide, and sulfur compounds (Mdoe & Anupam, 2021).

The flotation concentrate coal sample were dried by hot oven with the temperature of 105 °C for 24 hours and the dried product measured by electronic balance. Finally, weigh one gram of raw blended coal and one gram of concentrate coal from each particle size, frother dosage, and flotation time parameter. Use different crucibles for the samples: +63 -125 µm, +125 -250µm, and +250 - 500µm. After weighing, place the samples in the furnace and burn them for two hours at a temperature of 750°C. Once the burning process is complete, switch off the furnace and allow the burned ash to cool. After one day measure the burned ash within crucible to get the ash content of the raw coal sample and concentrate coal for each particle size sample. Figure 25 below shows treated coal before burning with furnace(a) in the time burning with furnace (b) and the ash of coal after burning at a temperature of 750°C for two hours.

a) b) c)

Figure 25 Shows the ash content of coal after burned with the furnace at a temperature of 750°C The following formula is used to determine the amount of ash

$$\text{Ash content} = \frac{\text{weight of ash residue after burning (g)}}{\text{weight of sample taken in (g)}}\ x100\%$$

Table 6 below shows the ash content and weight of coal at different particle size

Type of sample	Particle size distribution	Amount of sample taken in gram	Weight of ash (g)	Ash content (%)	Weight of coal 1-wt of ash in (g)
Raw blended coal	-	1.00	0.3181	31.81	0.6819
Treated coal	+63+-125 µm	1.00	0.1994	19.94	0.8006
	+125+-250 µm	1.00	0.1748	17.48	0.8252
	+250+-500 µm	1.00	0.1439	14.39	0.8561

A. Grade – recovery relation ship

The most common indicators of metallurgical efficiency are recovery and concentrate grade, and both must be known in order to assess a particular operation in general, recovery and concentrate grade are inversely correlated; as recovery raises, grade falls, and vice versa. The tailings assays are higher and the recovery is lower if an effort is made to achieve a very high-grade concentrate. More gangue will be present in the concentrate, and the concentration ratio and concentrate grade will drop if high metal recovery is the goal. It is impossible to provide representative recoveries and concentration ratios (Wills & Finch, 2016).

Grade: refers to the concentration of valuable mineral in the ore expressed as in percentage the ratio of valuable component to the total mass of the ore

$$\text{Grade} = \frac{Mass\ of\ valuable\ cmponenet}{\text{total mass of the ore}}\ x100\%$$

Recovery: is a measure of the percentage of valuable minerals that are successfully extracted from the ore during the mineral processing operation it is calculated as the ratio of the mass of valuable minerals in the concentrate to the mass of valuable minerals in the feed ore, expressed as a percentage.

$$\text{Recovery} = \frac{\text{mass of valuable minerals in the concentrate}}{\text{mass of valuable miniral in the feed}}\ x100\%$$ (*Tons of Concentrate M*, n.d.)

To calculate the recovery of coal for each flotation parameter investigated in this project after final flotation time using Mass balance. We can calculate the Mass of coal in the concentrate, Mass of coal in the feed, the Mass of coal in the Tailing and the mass of tailing

B. Mass balance in different particle size

In the flotation process ash is considered as the impurities in the coal. Using mass balance, the Percentage of pure coal is calculated both in the concentrate and in the tailing. The fig 26 below shows the mass balance of the flotation process.

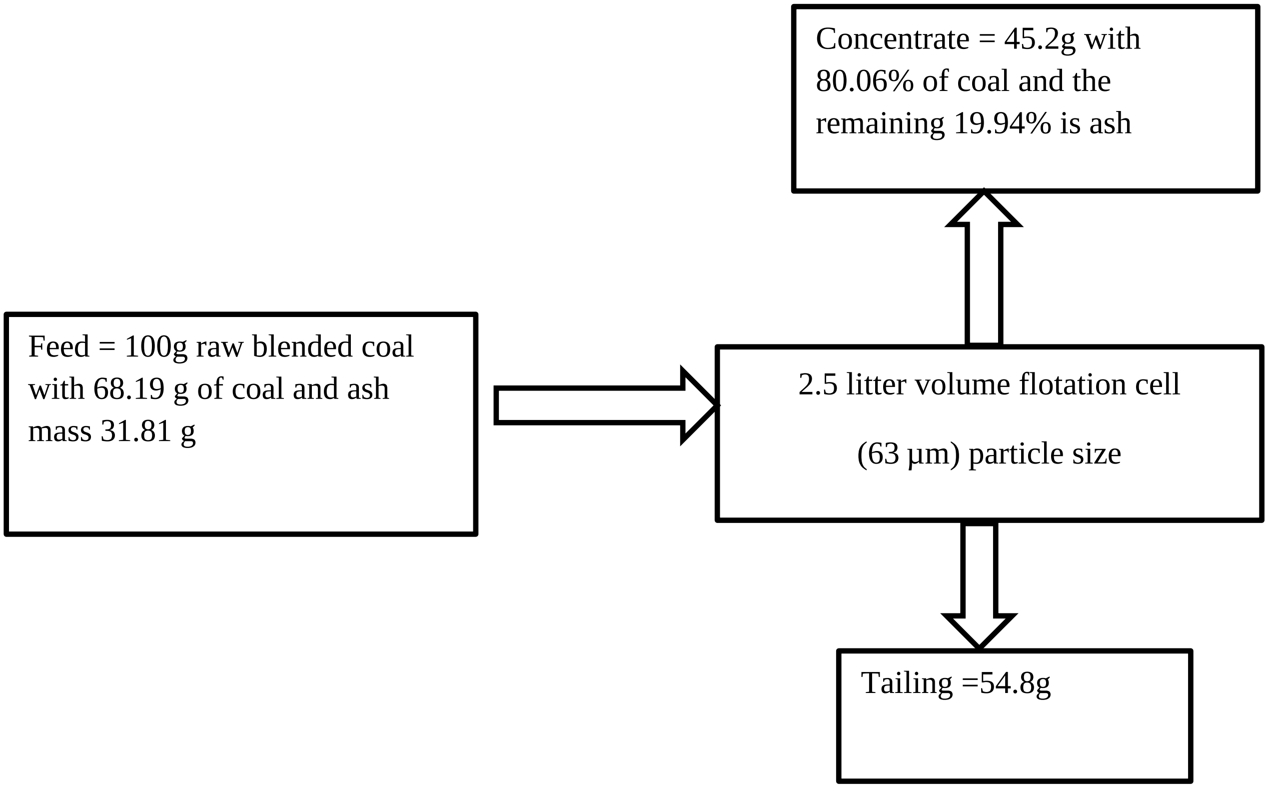


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Figure 26 Shows material balances of the flotation experimental process

Table 7 below shows mass of concentrate and tailing

Reagent			**Flotation time (minute)**	**Mass of Feed (g)**	**Particle size distribution**	**Mass in gram**	
Frother (n-octanol)	**Collector (kerosene)**	**Depressant (sodium silicate)**				**Concentrate**	**Tailing**
3ml	10ml	1.5ml	10	100	+63+-125 μm	45.2	54.8
					+125+-250 μm	29.5	70.5
					+250+-500 μm	19.3	80.7

From the figure 26 Total mass balance for solid material, ash mass, pure coal mass

A.for particle size 63 μm fraction

- Total mass balance for solid material

$Mass\ in\ the\ feed = \text{Mass in the concentrate(C)} + \text{Mass in the tailing(T)}$ (*Tons of Concentrate M*, n.d.)

$$100\text{g} = 45.2\text{g} + \text{T}$$

$$\text{T} = 54.8\text{g}$$

- Material balance for Ash content

$$Ash\ mass\ in\ the\ feed = \text{Ash mass in the concentrate} + \text{Ash mass in the tailing}$$

$$(0.3181gx100g)\% = (0.1994\text{g}\text{x}45.2\text{g})\% + (\text{Ash content})\text{x}54.8\text{g}$$

$$31.81 = 9.012 + (\text{Ash content})\text{x}54.8\text{g}$$

$$Ash\ content\ in\ the\ tailing\ = 41.60\%$$

- Material balance for pure coal content

$pure\ coal\ mass\ in\ the\ feed = \text{pure coal mass in the concentrate} + \text{pure coal mass in the tailing}$ (*Tons of Concentrate M*, n.d.)

$$(100 - 31.81\%)x100g = (100 - 19.94\%)\text{x}45.2 + \text{pure coal content in the tailing}(\%)\text{x}54.8\text{g}$$

$$pure\ coal\ content\ in\ the\ tailing\ = 58.39\%$$

B.for particle size 125 µm fraction

- Total mass balance for solid material

$$Mass\ in\ the\ feed = \text{ Mass in the concentrate(C)} + \text{Mass in the tailing(T)}$$

100g = 29.5g + T

T =70.5g

- Material balance for Ash content

$$Ash\ mass\ in\ the\ feed = \text{Ash mass in the concentrate} + \text{Ash mass in the tailing}$$

$$(0.3181x100g)\% = (0.1748\text{x}29.5\text{g})\% + \text{Ash content x } 70.5\text{g}$$

$$Ash\ content\ in\ the\ tailing = 37.80\%$$

- Material balance for pure coal content

$$pure\ coal\ mass\ in\ the\ feed = \text{pure coal mass in the concentrate} + \text{pure coal mass in the tailing}$$

$$(100 - 31.81\%)x100g = (100 - 17.48\%)\text{x}29.5 + \text{pure coal content in the tailing}(\%)\text{x}70.5\text{g}$$

$$pure\ coal\ content\ in\ the\ tailing\ = 62.19\%$$

C. for particle size 250 µm fraction

- Total mass balance for solid material

$Mass\ in\ the\ feed = \text{ Mass in the concentrate(C)} + \text{Mass in the tailing(T)}$ (*Tons of Concentrate M*, n.d.)

100g = 19.3g + T

T =80.7g

- Material balance for Ash content

$$Ash\ mass\ in\ the\ feed = \text{Ash mass in the concentrate} + \text{Ash mass in the tailing}$$

$$(0.3181x100g)\% = (0.1439\text{ x}19.3\text{g})\% + \text{Ash content x } 80.7\text{g}$$

$$Ash\ content\ in\ the\ tailing = 29.03\%$$

- Material balance for pure coal content

$$pure\ coal\ mass\ in\ the\ feed = \text{pure coal mass in the concentrate} + \text{pure coal mass in the tailing}$$

$$(100 - 31.81\%)x100g = (100 - 14.39\%)\text{x}19.3 + \text{pure coal content in the tailing}(\%)\text{ x }80.7\text{g}$$

$$pure\ coal\ content\ in\ the\ tailing\ = 64.02$$

Table 9 shows the ash content of coal in the concentrate and tailing

Flotation time(minutes)	Particle size distribution	Mass of feed (g)	Mass in gram		Ash content in (%)	
			Concentrate in (g)	Tailing in (g)	Concentrate	Tailing
10	+63+-125 µm	100	45.2	54.8	19.94	41.60
	+125+-250 µm	100	29.5	70.5	17.48	37.80
	+250+-500 µm	100	19.3	80.7	14.39	29.03

4.2.3 Determination of Grade and Recovery in Different Particle Size

To find out the recovery of the blended coal first calculate the mass of coal in the raw feed, mass of coal in the concentrate, in three operational parameters based on the data of ash (particle size, frother dosage, time)

Mass of coal in the feed and in the concentrate in 63 µm

- Mass of the raw sample 100g with 68.19 % of coal the remaining 31.81 % is ash content
- Mass of coal in the raw feed sample is 0.6819 *100g = 68.19 g
- Mass of ash in the raw feed sample is 0.3181g*100g = 31.81 g
- Mass of concentrate 45.2 g with 80.06% of coal the remaining 19.94% of ash content
- Mass of coal in the concentrate is 45.2 *0.806 = 36.43g
- Mass of ash in the concentrate 45.2* 0.194 = 9.012 g
- Mass of tailing is 100 – 45.2 = 54.8g
- Percentage of ash in the concentrate is reduced by 31.81 – 19.94 = 11.87%

Mass of coal in the feed and in the concentrate in 125 µm

- Mass of the raw sample 100g with 68.19 % of coal the remaining 31.81 % is ash content

- Mass of coal in the raw feed sample is 0.6819g *100g = 68.19 g
- Mass of ash in the raw feed sample is 0.3181g*100g = 31.81 g
- Mass of concentrate 29.5 g with 82.52% of coal the remaining 17.48% of ash content
- Mass of coal in the concentrate is 29.5g *0.8252g = 24.3434g
- Mass of ash in the concentrate 29.5* 0.1748 = 5.1566 g
- Mass of tailing is 100 – 29.5 = 70.5g
- Percentage of ash in the concentrate is reduced by 31.81 – 17.48 = 14.33%

Mass of coal in the feed and in the concentrate in 250 µm

- Mass of the raw sample 100g with 68.19 % of coal the remaining 31.81 % is ash content
- Mass of coal in the raw feed sample is 0.6819 *100g = 68.19 g
- Mass of ash in the raw feed sample is 0.3181*100g = 31.81 g
- Mass of concentrate 19.3 g with 85.61% of coal the remaining 14.39% of ash content
- Mass of coal in the concentrate is 19.3g *0.8561g = 16.522g
- Mass of ash in the concentrate 19.3* 0.1439 = 2.777g
- Mass of tailing is 100 – 19.3 = 80.7g
- Percentage of ash in the concentrate is reduced by 31.81 – 14.39 = 17.42%

Table 8 Shows Grade and recovery of batch flotation cell experiment in different particle size

Type of sample	Particle size	Yield (%)	Mass of coal in the concentrate (g)	Mass of coal in the feed(g)	Recovery of coal (%)	Grade of coal (%)	Ash in (%)
Raw blended coal	-	-	-	68.19	-	68.19	31.81
Treated	+63+-125 µm	45.2	36.187	68.19	53.067	80.06	19.94
	+125+-250 µm	29.5	24.3434	68.19	35.699	82.52	17.48
	+250+-500 µm	19.3	16.522	68.19	24.22	85.61	14.39

In the flotation of fine and coarse particles, the attachment of fine particles and the detachment of coarse particles are the main problems because of differences in contact angles during collision and detachment, respectively. Since the kinetic energy of coarse particles is greater than the energy required to separate them from the gas-liquid contact, they have a detachment problem (Patnaik et al., 2020). According to global coal flotation practices, the optimal particle size in coal flotation is usually less than 0.6/0.5 mm or < 0.25mm. Fine and coarse coal flotation recoveries behave differently. The changes of surface hydrophobicity have a more pronounced effect on the recovery of coarse particles than on the fine particles. Maximum coal recovery obtained from the 75 to 300 µm particle size range (Sokolovic & Miskovic, 2018).However, in this study as the particle size increase from +63 +-125 µm to +250+-500 µm see figure 27 below the rate of recovery decrease because of the detachment of the particle from the bubble increase. So, the optimum particle size which have high combustible recovery and yield much less ash content in the project is +125 µm + -250µm rather than the two particle sizes.

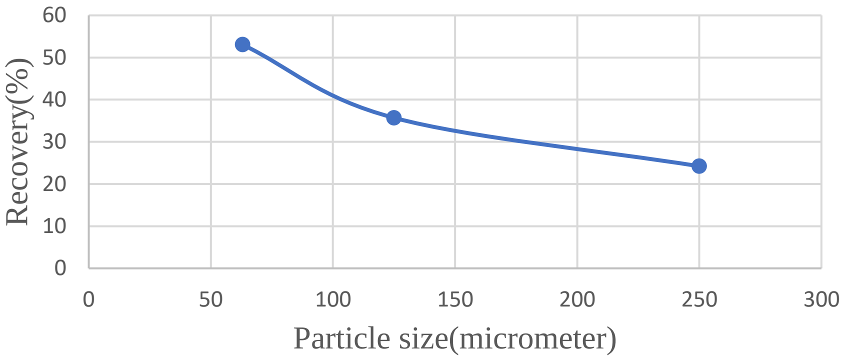

Figure 27 Shows recovery versus particle size in flotation experiment

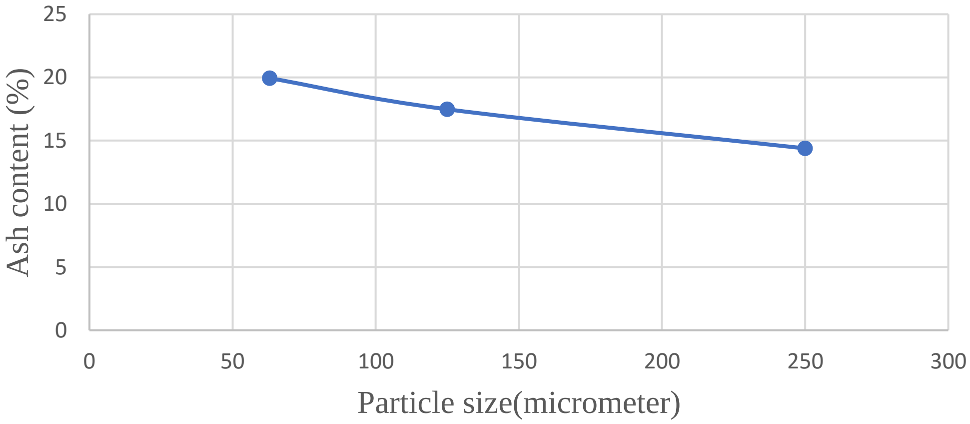

Figure 28 Shows the effect of particle size on ash formation

When particles are close bubbles, the bubbles can readily catch them. This results from the interaction of fluid flow with micro hydrodynamic force. Therefore, it's critical to examine the fluid flow to guarantee that the particles and bubbles are close together. Particle size affects the collision efficiency of particles with bubbles. Turbulence primarily controls the collision of tiny particles. They have a low mass, which is why. When fine particles collide, the effects of gravity and inertial forces are negligible. Both mass and inertia are greater for the coarse particles. When coarse particles collide, the inertial, gravitational, and interceptional mechanisms are crucial. A mixture of coarse and fine particles is to be expected in a real-world situation. Controlling particle collisions is a challenging task. It is therefore still an open problem that requires attention both in the lab and in the field. The large mass of particles causes the turbulence effects to be ignored (Patnaik et al., 2020). See figure 28 above the ash content of +250+-500 µm particle size is yield much less ash content than the two fine particle size (+63 +-125 µm and +125 +-250µm). Because coarse particle size maintains their detachment during turbulence compare to the fine size. This leads to low ash content in the recovered product.

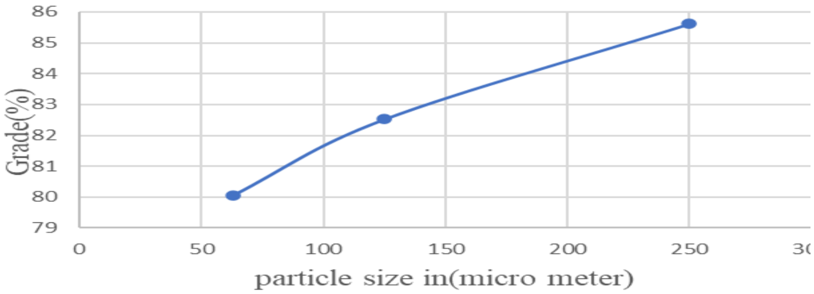

Figure 29 Shows the effect of particle size on Grade of coal

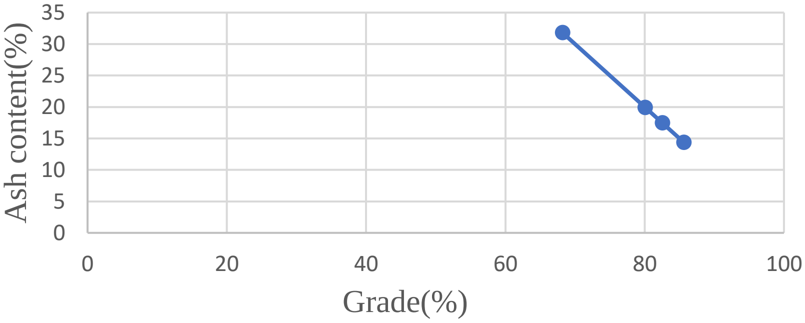

Figure 30 Shows ash content versus grade of blended coal in different particle size

4.2.4 Determination of Ash Content in Different Frother Dosage

The flotation concentrate coal sample were dried by hot oven with the temperature of 105 °C for 24 hours and the dried product measured by electronic balance. Finally, from the dried sample weigh one gram 1-gram raw blended coal, and1gram of concentrate coal from each frother dosage (3ml, 6ml,9ml) using different crucibles, after this the samples put in to the furnace and burned for two hours at a temperature of 750°C switch of the furnace and cool the burned ash. After one day measure the burned ash within crucible to get the ash content for the raw coal sample and each frother dosage coal sample using the formula:

$$\text{Ash content} \;=\frac{\text{weight of ash residue after burning (g)}}{\text{weight of sample taken in (g)}}\; x100\%$$

Table 11 Shows the ash content and weight of coal at different frother dosage

Type of sample	Dosage of frother (n-octanol)	Amount of sample taken (g)	Weight of ash in (g)	Ash content (%)	Weight of coal 1-wt of ash in (g)
Raw blended coal	-	1:00	0.3181	31.81	0.6819
Treated coal	3ml	1.00	0.2075	20.75	0.7925
	6ml	1.00	0.1746	17.46	0.8254
	9ml	1.00	0.2397	23.97	0.7603

C/ Mass balance in different n-octanol dosage

Mass balance calculations are used to determine the amount of ash percentage in the tailing and pure coal percentage in the tailings produced by the flotation process. In this process, ash is considered the primary impurity in the coal. The fig 31 below illustrates the mass balance of the flotation process at different frother dosages.

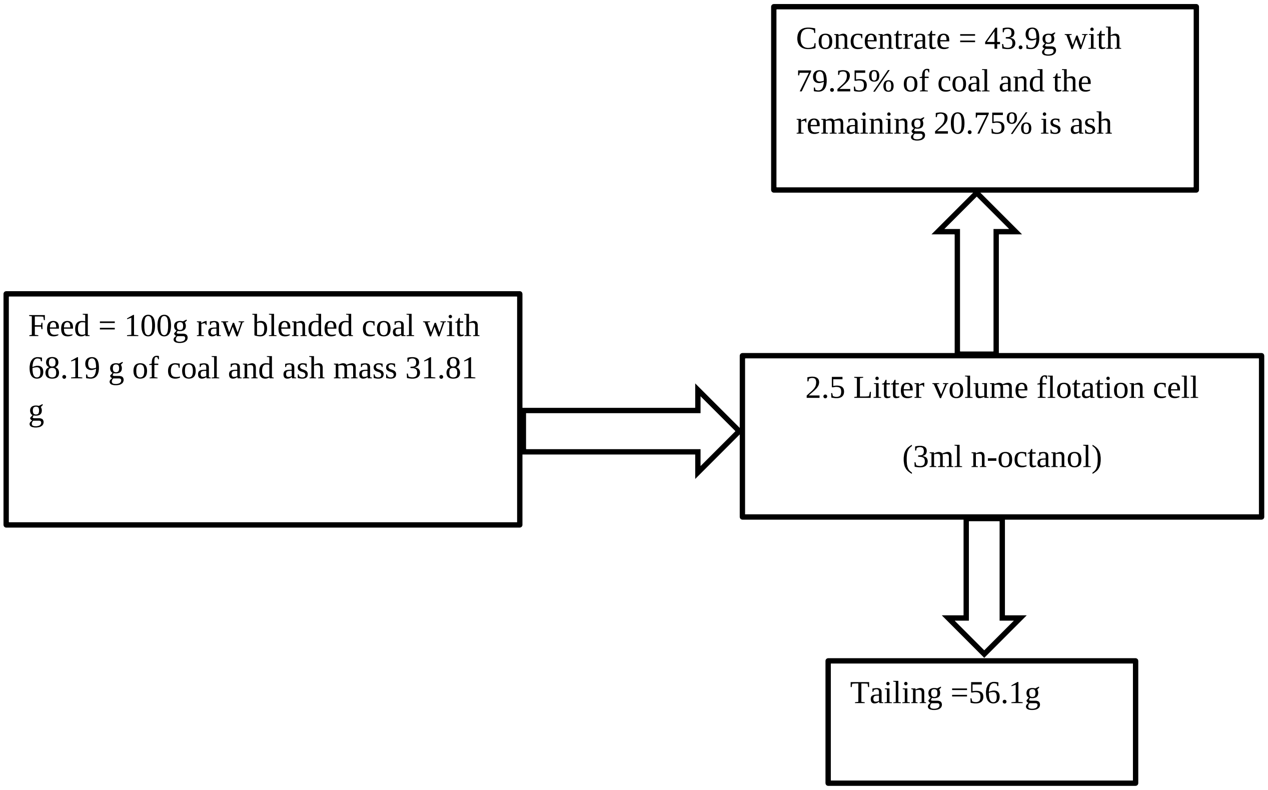

Figure 31 Shows material balances of the flotation experimental process in 3ml n-octanol

Table 12 Batch flotation experiment mass of concentrate and tailing

Particle size	Collector (kerosene)	Depressant (sodium silicate)	Flotation time (minute)	Mas of feed (g)	Dosage of frother (n-octanol)	Mass in gram	
						Concentrate in (g)	Tailing in (g)
+125+-250µm	10ml	1ml	10	100	3ml	43.9	56.1
					6ml	55.6	44.4
					9ml	45.5	54.5

A. Material balance calculation for 3ml n-octanol

- Total mass balance for solid material

$Mass\ in\ the\ feed = Mass\ in\ the\ concentrate(C) + Mass\ in\ the\ tailing(T)$ (*Tons of Concentrate M*, n.d.)

$$100g = 43.9g + T$$

$$T = 56.1g$$

- Material balance for ash content

$$Ash\ mass\ in\ the\ feed = \text{Ash mass in the concentrate} + \text{Ash mass in the tailing}$$

$$(0.3181x100g)\% = (0.2075\text{x}43.9\text{g})\% + (\text{Ash content})\text{x}56.1\text{g}$$

$$31.81\% = 9.109 + (\text{Ash content})\text{x}56.1\text{g}$$

$$Ash\ content\ in\ the\ tailing = 40.46\%$$

- Material balance for pure coal content

$$pure\ coal\ mass\ in\ the\ feed = \text{pure coal mass in the concentrate} + \text{pure coal mass in the tailing}$$

$$(100 - 31.81\%)x100g = (100 - 20.75\%)\text{x}43.9\text{g} + \text{pure coal content in the tailing}(\%)\ \text{x}\ 56.1\text{g}$$

$$pure\ coal\ content\ in\ the\ tailing = 59.53\%$$

B. Material balance calculation for 6ml n-octanol

$Mass\ in\ the\ feed = \text{Mass in the concentrate(C)} + \text{Mass in the tailing(T)}$ (*Tons of Concentrate M*, n.d.)

100g = 55.6g + T

T = 44.4g

- Material balance for ash content

$$Ash\ mass\ in\ the\ feed = \text{Ash mass in the concentrate} + \text{Ash mass in the tailing}$$

$$(0.3181x100g)\% = (0.1746 \text{ x } 55.6\text{g})\% + (\text{Ash content})\text{x } 44.4\text{g}$$

$$31.81\% = 9.109 + (\text{Ash content})\text{x}56.1\text{g}$$

$$Ash\ content\ in\ the\ tailing\ = 49.77\%$$

- Material balance for pure coal content

$$pure\ coal\ mass\ in\ the\ feed = \text{pure coal mass in the concentrate} + \text{pure coal mass in the tailing}$$

$$(100 - 31.81\%)x100g = (100 - 17.46\%)\text{x } 55.6 \text{ g} + \text{pure coal content in the tailing(\%) x } 44.4\text{g}$$

$$pure\ coal\ content\ in\ the\ tailing\ = 50.22\%$$

C. Material balance calculation for 9ml n-octanol

Mass in the feed (F) = Mass in the concentrate(C) + Mass in the tailing (T)

100g = 45.5.g + T

T = 54.5g

- Material balance for ash content

$$Ash\ mass\ in\ the\ feed = \text{Ash mass in the concentrate} + \text{Ash mass in the tailing}$$

$$(0.3181x100g)\% = (0.2397 \text{ x } 45.5\text{g})\% + (\text{Ash content})\text{x } 54.5\text{g}$$

$$31.81\% = 10.906 + (\text{Ash content})\text{x}56.1\text{g}$$

$$Ash\ content\ in\ the\ tailing\ = 38.35\%$$

- Material balance for pure coal content

$$pure\ coal\ mass\ in\ the\ feed = \text{pure coal mass in the concentrate} + \text{pure coal mass in the tailing}$$

$$(100 - 31.81\%)x100g = (100 - 23.97\%)\text{x } 45.5 \text{ g} + \text{pure coal content in the tailing(\%) x } 54.5\text{g}$$

$$pure\ coal\ content\ in\ the\ tailing\ = 61.64\%$$

Table 13 Shows the ash content of coal in the concentrate and tailing

Particle size	**Dosage of frother (n-octanol)**	**Mass of feed (g)**	**Mass in gram**		**Ash content in (%)**	
			Concentrate in (g)	**Tailing in (g)**	**Concentrate**	**Tailing**
+125+-250µm	3ml	100	43.9	56.1	20.75	40.46
	6ml	100	55.6	44.4	17.46	49.77
	9ml	100	45.5	54.5	23.97	38.35

4.2.5 Determination of Grade and Recovery in Different n-octanol Dosage

For calculating the recovery of coal, it is crucial to determine the mass of coal in the feed, the mass of coal in the concentrate is important. Knowing the mass of ash in the raw feed, the mass of ash in the concentrate, the percentage of ash in the tailings and percentage of ash in the concentrate is also crucial to compare the raw and treated coal.

Mass of coal in the feed and in the concentrate in 3ml n-octanol

- Mass of the raw sample 100g with 68.19 % of coal the remaining 31.81 % is ash content
- Mass of coal in the raw feed sample is 0.6819 *100g = 68.19 g
- Mass of ash in the raw feed sample is 0.3181*100g = 31.81 g
- Mass of concentrate 43.9 g with 79.25% of coal the remaining 20.75% of ash content
- Mass of coal in the concentrate is 43.9g *0.7925g = 34.790g
- Mass of ash in the concentrate 43.9* 0.2075 = 9.109g
- Mass of tailing is 100 – 43.9 = 56.1g
- Percentage of ash in the concentrate is reduced by 31.81 – 20.75 = 11.06%

Mass of coal in the feed and in the concentrate in 6ml n-octanol

- Mass of the raw sample 100g with 68.19 % of coal the remaining 31.81 % is ash content
- Mass of coal in the raw feed sample is 0.6819 *100g = 68.19 g
- Mass of ash in the raw feed sample is 0.3181*100g = 31.81 g
- Mass of concentrate 55.6 g with 82.54% of coal the remaining 17.46% of ash content
- Mass of coal in the concentrate is 55.6g *0.8254g = 45.892g
- Mass of ash in the concentrate 55.6g* 0.1746= 9.707g

- Mass of tailing is 100 – 55.6 = 44.4g
- Percentage of ash in the concentrate is reduced by 31.81 – 17.46 = 14.35%

Mass of coal in the feed and in the concentrate in 9ml n-octanol

- Mass of the raw sample 100g with 68.19 % of coal the remaining 31.81 % is ash content
- Mass of coal in the raw feed sample is 0.6819 *100g = 68.19 g
- Mass of ash in the raw feed sample is 0.3181*100g = 31.81 g
- Mass of concentrate 45.5 g with 76.03% of coal the remaining 23.97% of ash content
- Mass of coal in the concentrate is 45.5g *0.7603g = 34.5936
- Mass of ash in the concentrate 45.5* 0.2397 = 10.906g
- Mass of tailing is 100 – 45.5= 54.5g
- Percentage of ash in the concentrate is reduced by 31.81 – 23.97 = 7.84

Table 14 Shows Grade and recovery of blended coal in different frother dosage

Type of sample	Frother dosage	Yield (%)	Mass of coal in the concentrate (g)	Mass of coal in the feed	Recovery of coal (%)	Grade of coal (%)	Ash in (%)
Raw blended coal	-	-	-	68.19	-	68.19	31.81
Treated	3ml	43.9	34.790	68.19	51.020	79.25	20.75
	6ml	55.6	45.892	68.19	67.300	82.54	17.46
	9ml	45.5	34.5936	68.19	50.731	76.03	23.97

Bubble-particle collision efficiency, bubble-particle attachment efficiency, and the quantity of bubbles produced all increase with decreasing bubble size. These factors may result in higher water recovery, which raises the entrainment of gangue minerals, but they also increase the flotation rate of fine particles (Patnaik et al., 2020). a low dosage of Frother resulted in unstable froth and insufficient interactions between bubbles and particles, ultimately causing reduced recovery rates. Insufficient Frother can lead to inadequate froth stability, which in turn reduce the recovery of valuable minerals (Akbari, 2009). See the figure 32 below initially the frother dosage increase the rate of recover in the froth flotation experiment increase 3ml to 6 ml indicates there is the formation of smaller bubbles beneficial to capturing to the fine particle and good particle - bubble contact in the froth but after 6ml(n-octanol) the recovery rate becomes decline. See figure 32 indicates higher frother dosage increase the slurry viscosity making difficult the bubble to rise and carry the coal particles to the surface that results lower recovery rate. The optimum frother dosage is 6ml n-octanol shown in the fig 32 and 33 below respectively.

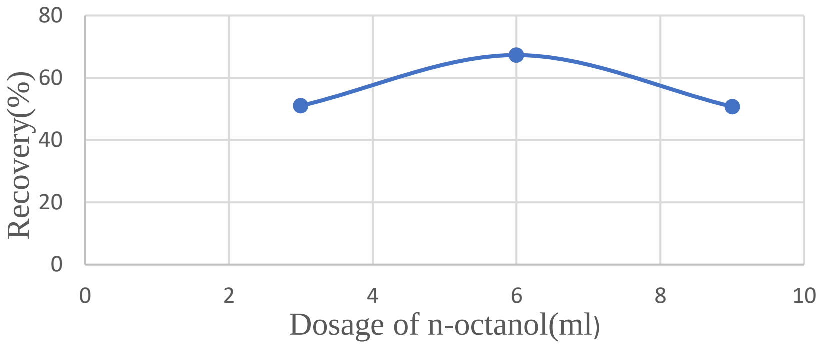

Figure 32 Shows recovery versus frother dosage

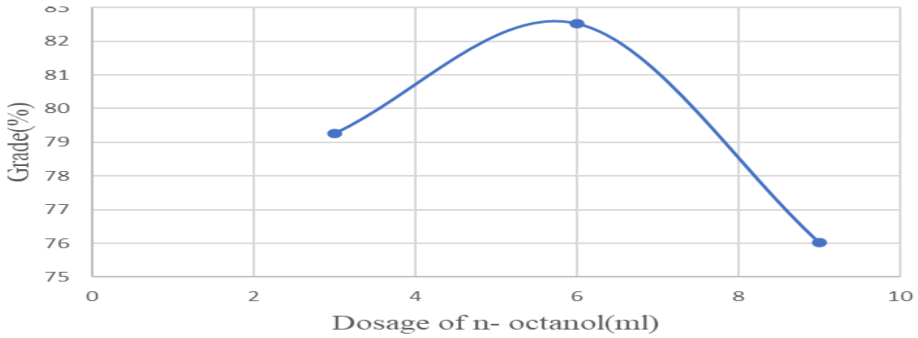

Figure 33 Shows grade versus frother dosage

The type of frother is essential to the flotation of fine bituminous coal. MIBC > Dowfroth200 > 4-Methilo-2-Pentanol is the flotation efficiency order of the tested frothers. Using MIBC as a floating bituminous coal with a PSD of 80% passing 75 µm produced the best combustible recovery and ash content. Diesel, SIBX, and a frother acting as co-collectors at PH 6.The efficiency of MIBC demonstrated that when it comes to floating fine bituminous coal, it is the best frother (Nethamba et al., 2022). The figure 33 shows increasing the dosage of n-octanol 3ml to 6ml increase the grade of blended coal this indicates there is improving bubble stability, increasing hydrophobicity and optimizing froth quality that enables better separation of coal from ash resulting higher quality of coal. But after 6ml dosage of n-octanol the grade of blended coal becomes decline, this indicates excessive frother over stabilize the air bubbles and decrease the selective attachment of the coal particles. allow more impurities float along the coal particles contributing to decrease the quality of coal.

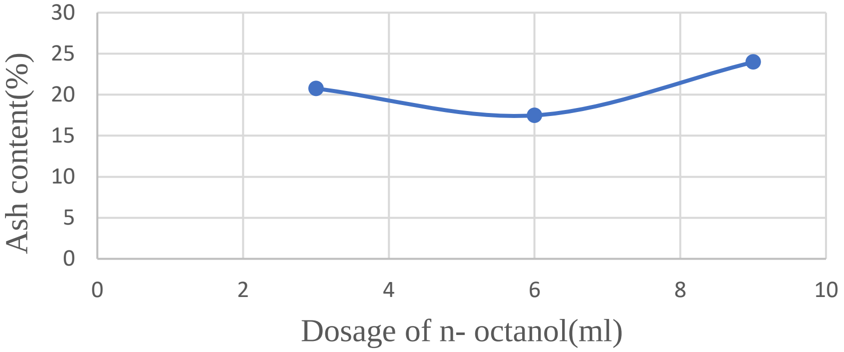

Figure 34 Shows ash content versus frother dosage in different frother dosage

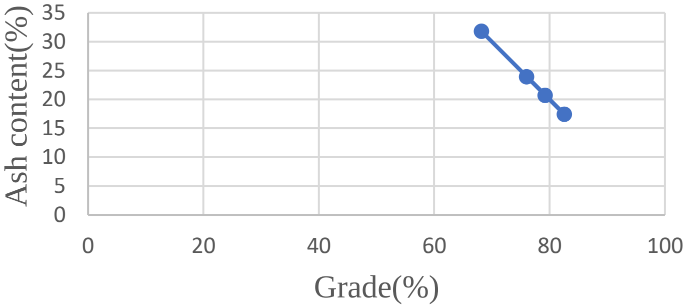

Figure 35 Shows Ash content versus grade in different frother dosage

4.2.6 Determination of Ash Content in Different Flotation Time

From the dried sample weigh one gram 1-gram raw blended coal, and1gram of concentrate coal from each flotation time (5minute,10minute,15minute) using different crucibles after this the samples put in to the furnace and burned for two hours at a temperature of 750°C switch of the furnace and cool the burned ash. After one day measure the burned ash within crucible to get the ash content of for the raw coal sample and each flotation time coal sample using the formula:

$$\text{Ash content} \ = \frac{\text{weight of ash residue after burning (g)}}{\text{weight of sample taken in (g)}} \ x100\%$$

Table 15 Shows the ash content and weight of coal at different flotation time

Type of sample	Flotation time(minute)	Amount of sample taken (g)	Weight of ash (g)	Ash content (%)	Weight of coal (1-wt of ash) in (g)
Raw blended coal	-	1.00	0.3181	31.81	0.6819
Treated coal	5	1.00	0.1968	19.68	0.8032
	10	1.00	0.214	21.4	0.786
	15	1.00	0.2206	22.06	0.7794

D/ Mass balance for different flotation time

Mass balance involves ensuring that the total mass entering a system equals the total mass leaving it, which is crucial for maintaining operational integrity in flotation circuits. In the flotation process, ash is an impurity in coal. Mass balance helps to calculate the percentage of pure coal both in the concentrate and tailings, as shown in the figure below.

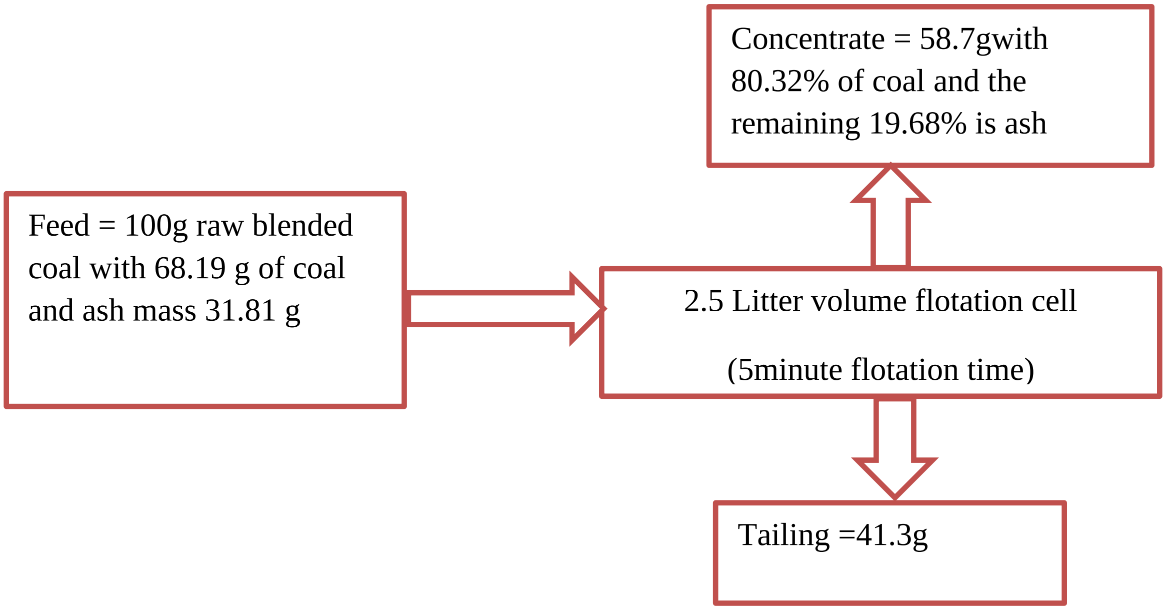

Figure 36 Shows material balance flotation process in different flotation time

Table 16 Mass of concentrate and tailing in batch flotation experiment in different flotation time

Particle size	**Reagent**			**Flotation time (minute)**	**Mass of feed (g)**	**Mass**	
	Collector (kerosene)	**Frother (n-octanol)**	**Depressant (Sodium silicate)**			**Concentrate in (g)**	**Tailing in (g)**
+125+-250µm	10ml	3ml	1ml	5	100	58.7	41.3
				10	100	61.1	38.9
				15	100	63.5	36.5

A. Material balance calculation in 5minute flotation time

Mass in the feed (F) = Mass in the concentrate(C) + Mass in the tailing (T) (*Tons of Concentrate M*, n.d.)

$$100g = 58.7g + T$$

$$T = 41.3g$$

- Material balance for Ash content

$$Ash\ mass\ in\ the\ feed = \text{Ash mass in the concentrate} + \text{Ash mass in the tailing}$$

$$(0.3181x100g)\% = (0.1968\text{ x }58.7\text{g})\% + (\text{Ash content})\text{x }41.3\text{g}$$

$$Ash\ content\ in\ the\ tailing\ = 49.05\%$$

- Material balance for pure coal content

$$pure\ coal\ mass\ in\ the\ feed = \text{pure coal mass in the concentrate} + \text{pure coal mass in the tailing}$$

$$(100 - 31.81\%)x100g = (100 - 19.68\%)\text{x }58.7\text{g} + \text{pure coal content in the tailing(\%) x }41.3\text{g}$$

$$pure\ coal\ content\ in\ the\ tailing\ = 50.94\%$$

B. Material balance calculation in 10minute flotation time

Mass in the feed (F) = Mass in the concentrate(C) + Mass in the tailing (T)

100g = 61.1g + T

T = 38.9 g

- Material balance for Ash content

$$Ash\ mass\ in\ the\ feed = \text{Ash mass in the concentrate} + \text{Ash mass in the tailing}$$

$$(0.3181x100g)\% = (0.214\text{ x }61.1\text{g})\% + (\text{Ash content})\text{x }38.9\text{g}$$

$$Ash\ content\ in\ the\ tailing\ = 48.16\%$$

- Material balance for pure coal content

$$pure\ coal\ mass\ in\ the\ feed = \text{pure coal mass in the concentrate} + \text{pure coal mass in the tailing}$$

$$(100 - 31.81\%)x100g = (100 - 21.4\%)\text{x }61.1\text{g} + \text{pure coal content in the tailing(\%) x }38.9\text{g}$$

$$pure\ coal\ content\ in\ the\ tailing\ = 51.84\%$$

C. Material balance calculation in 15minute flotation time

Mass in the feed (F) = Mass in the concentrate(C) + Mass in the tailing (T)

100g = 63.5g + T

T = 36.5 g

- Material balance for Ash content

$$Ash\ mass\ in\ the\ feed = \text{Ash mass in the concentrate} + \text{Ash mass in the tailing}$$

$$(0.3181x100g)\% = (0.2206\text{ x }63.5\text{g})\% + (\text{ash content})\text{x }36.5\text{g}$$

$$Ash\ content\ in\ the\ tailing\ = 48.77\%$$

- Material balance for pure coal content

$$pure\ coal\ mass\ in\ the\ feed = \text{pure coal mass in the concentrate} + \text{pure coal mass in the tailing}$$

$$(100 - 31.81\%)x100g = (100 - 22.06\%)\text{x }61.1\text{g} + \text{pure coal content in the tailing}(\%)\text{ x }36.5\text{g}$$

$$pure\ coal\ content\ in\ the\ tailing\ = 56.35\%$$

Table 17 Shows ash content of coal in the concentrate and tailing in different flotation time

Particle size	**Flotation time (minute)**	**Mass of feed (g)**	**Mass in gram**		**Ash content in (%)**	
			Concentrate in (g)	**Tailing in (g)**	**Concentrate**	**Tailing**
+125+-250µm	5	100	58.7	41.3	19.68	49.05
	10	100	61.1	38.9	21.4	48.16
	15	100	63.5	36.5	22.06	48.77

4.2.7 Determination of Grade and Recovery in Different Flotation Time

Calculating mass of coal in the feed, mass of coal in the concentrate is important to know the recovery of the coal.

Mass of coal in the feed and in the concentrate in 5-minute flotation time

- Mass of the raw sample 100g with 68.19 % of coal the remaining 31.81 % is ash content
- Mass of coal in the raw feed sample is 0.6819 *100g = 68.19 g
- Mass of ash in the raw feed sample is 0.3181*100g = 31.81 g
- Mass of concentrate 58.7 g with 80.32% of coal the remaining 19.68% of ash content
- Mass of coal in the concentrate is 58.7g * 0.8032g = 47.147g
- Mass of ash in the concentrate 58.7* 0.1968 = 11.552g
- Mass of tailing is 100 – 58.7 = 41.3g
- Percentage of ash in the tailing is 31.81 – 19.68 = 12.13%

Mass of coal in the feed and in the concentrate in 10-minute flotation time

- Mass of the raw sample 100g with 68.19 % of coal the remaining 31.81 % is ash content
- Mass of coal in the raw feed sample is 0.6819 *100g = 68.19 g
- Mass of ash in the raw feed sample is 0.3181*100g = 31.81 g
- Mass of concentrate 61.1 g with 78.60% of coal the remaining 21.4% of ash content
- Mass of coal in the concentrate is 61.1g * 0.7860g = 48.024g
- Mass of ash in the concentrate 61.1* 0.214 = 7.576g
- Mass of tailing is 100 – 61.1 = 38.9g
- Percentage of ash in the concentrate is reduced by31.81 – 21.40 = 10.41%

Mass of coal in the feed and in the concentrate in 15-minute flotation time

- Mass of the raw sample 100g with 68.19 % of coal the remaining 31.81 % is ash content
- Mass of coal in the raw feed sample is 0.6819 *100g = 68.19 g
- Mass of ash in the raw feed sample is 0.3181*100g = 31.81 g
- Mass of concentrate 63.5 g with 77.94% of coal the remaining 22.06% of ash content
- Mass of coal in the concentrate is 63.5g * 0.7794g = 49.491g
- Mass of ash in the concentrate 63.5g* 0.2206 = 14.008g
- Mass of tailing is 100 – 63.5 = 36.5g
- Percentage of ash in the concentrate is reduced by 31.81 – 22.06 = 9.75%

Table 9 Shows grade and recovery of coal in batch flotation experiment at different flotation time

Type of sample	**Flotation time in (minute)**	**Yield (%)**	**Mass of coal in the concentrate (g)**	**Mass of coal in the feed**	**Recovery of coal (%)**	**Grade of coal (%)**	**Ash in (%)**
Raw blended coal	-	-	-	68.19	-	68.19	31.81
Treated	5	58.7	47.147	68.19	69.140	80.32	0.1968
	10	61.1	48.024	68.19	70.426	78.60	0.214
	15	63.5	49.491	68.19	72.579	77.94	0.2206

When a sample of low-grade coal was floated, the recovery and coal concentrate grade rise as the flotation period increased. As the floating time extended from 5 to 20 minutes, the coal recovery rise from 65% to 85%. In the same time frame, the coal concentrate's grade also improved, rising from 55% to 65%. The enhanced particle-bubble attachment and increased impurity removal from the coal are responsible for the rise in recovery and grade of the coal concentrate as flotation time increases. A longer flotation time may not always result in additional process improvements, thus it's crucial to identify the optimal time range to guarantee the most effective and economical operation (Asiva Noor Rachmayani, 2015). Over prologed flotation time diminish the selectivity of the flotation process.Intialy threre is effective flotation process as the hydrophobic coal particles attached to the bubble while the hydrophilic particles remain in the sllury. Over flotation time can change the bihavior of froth affect the froth stability unstable froth not effectively separate the coal particles from impurities leads to more ash included in the concentrate resuls increase the ash contents of the coal that decerease the quality. So,in this study the optimal flotation timed I obtained maximun combustible recoovery and good quality is 10 minute see in the figure below.

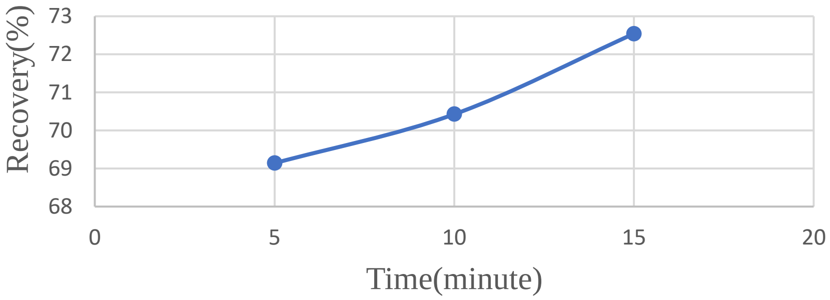

Figure 37 Shows recovery versus flotation time

As shown in Fig. 37 above, the recovery rate increases with flotation time. This is due to the extended interaction between coal particles and bubbles, which enhances the likelihood of particle attachment and leads to higher recovery rates. Additionally, longer flotation times provide a better opportunity for coal particles to utilize the available bubble surface area. The relationship between coal particle size and bubble size is also critical; smaller bubbles, which have a larger surface area for attachment, contribute to achieving higher recovery rates.

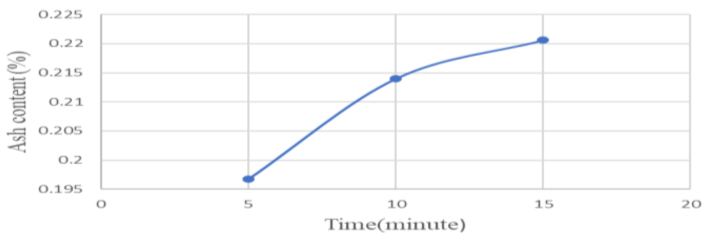

Figure 38 Shows ash content versus flotation time

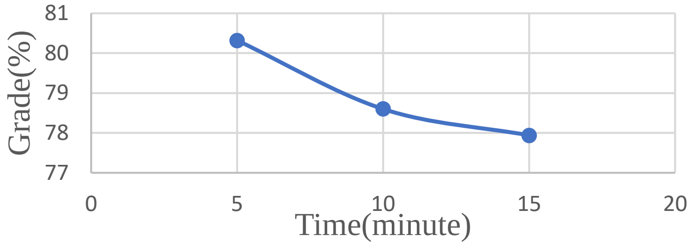

Figure 39 Shows grade versus flotation time

Fig 39 above shows as the flotation time increase the grade of the concentrate coal becomes decrease because of high chance of the non -hydrophobic particles raise to the surface and taken as a product that results decreasing the quality of the concentrated coal.

4.3 Coal Quality Improvement (Summary)

Table 10 Shows quality improvement of raw and treated coal in different particle size

Type of sample	**Particle size**	**Recovery (%)**	**Calorific value (Cal/gram)**
Raw	-	-	4,914.73
Treated	+63+-125 µm	53.067	5,865.0999
	+125+-250 µm	35.699	6,047.5781
	+250+-500 µm	24.22	6,227.4291

Table 11 Shows quality improvement of raw and treated coal in different frother dosage

Type of sample	**Dosage of n-octanol**	**Recovery (%)**	**Calorific value (Cal/gram)**
Raw	-	-	4,914.73
Treated	3ml	51.020	6,277.5867
	6ml	67.300	6,412.7735
	9ml	50.731	5,754.0365

Table 12 Shows quality improvement of raw and treated coal in different flotation time

Type of sample	Flotation time	Recovery (%)	Calorific value (Cal/gram)
Raw	-	-	4,914.73
Treated	5minute	69.140	6,141.9223
	10minute	70.426	5,894.4779
	15minute	72.542	5,894.2391

4.2 Proximate analysis

Table 13 Shows the quality improvement of coal before and after treatment

Type of sample	Proximate results (%)			Sulfur content (%)	Fixed carbon content (%)
	Volatile matter (%)	Moisture content (%)	Ash content (%)		
Raw	24.03	15.85	31.81	0.68	27.63
Treated	19.29	2.75	17.46	0.44	60.06

4.3.1 Moisture Content

The moisture content of the obtained result of the raw coal sample is 15.85% this reduces the carbon content of the coal that leads to lower heating value and higher transportation coasts and storage. But after treated by froth flotation technique the moisture content of the blended coal becomes reduced in all flotation parameters investigated in this project. As shown (Fig 40, 41 and 42) respectively the moisture content of treated blended coal at different particle size, different frother dosage and different flotation time.

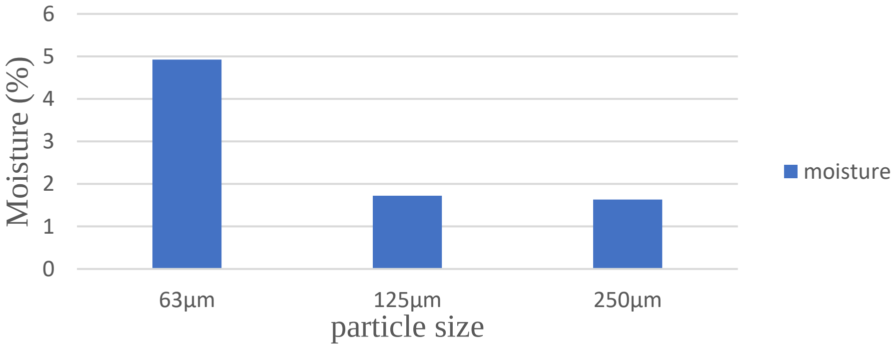

Figure 40 Shows moisture content of treated coal at different particle size

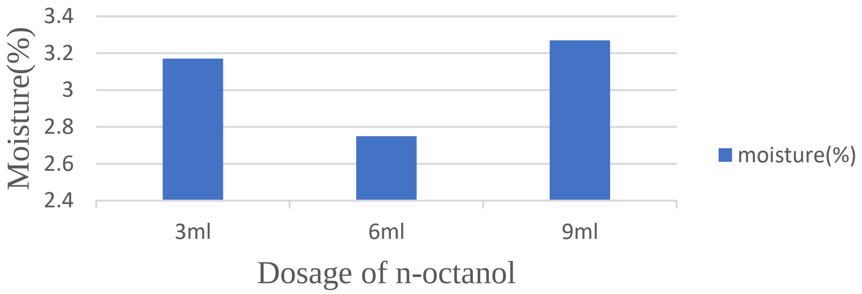

Figure 41 Shows moisture content of treated coal at different n-octanol dosage

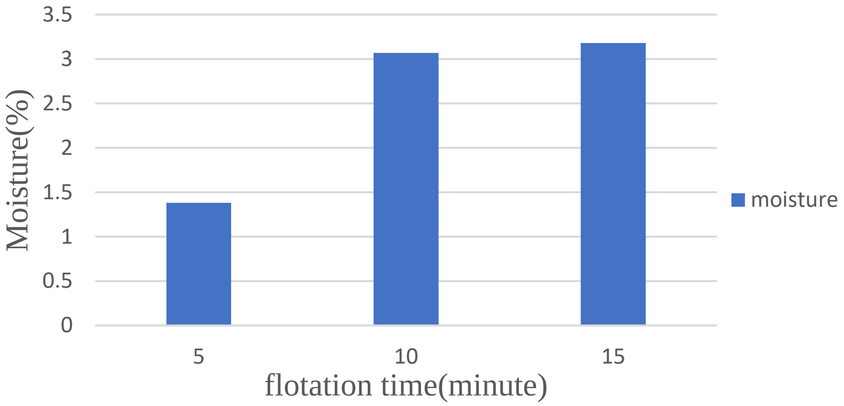

Figure 42 Shows moisture content of treated coal in different flotation time

4.3.2 Ash Content

Increases in ash content leads to a decrease in the quality or rank of coal. The quantity and behavior of ash at elevated temperatures significantly impact the type and design of ash handling systems utilized in the coal business. High temperatures cause coal ash to become sticky, ultimately transforming it into molten slag. This results in considerable slagging, decreased burning capacity, increased handling costs, and decreased combustion efficiency (Turap et al., 2015).In this study the ash content of the raw blended coal was 31.81% but after treated the ash content of the coal becomes reduced in the three flotation parameters(particle size, frother dosage, flotation time). figure 43,44 and 45 below show the ash content of treated blended coal in different flotation parameters.

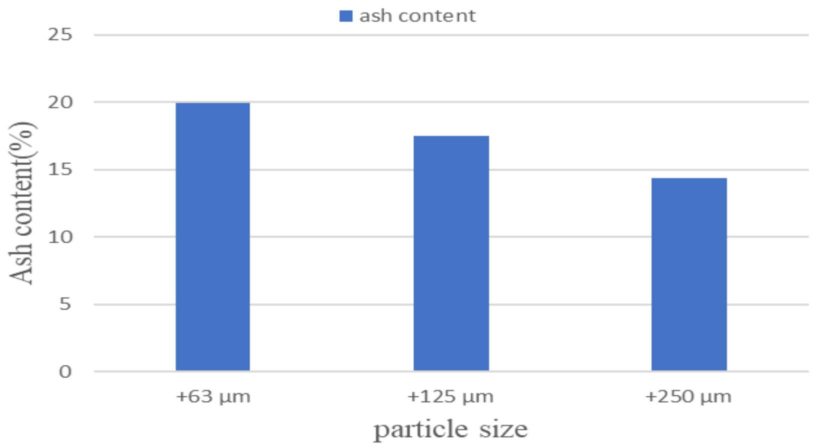

Figure 43 Shows the ash content of different particle size

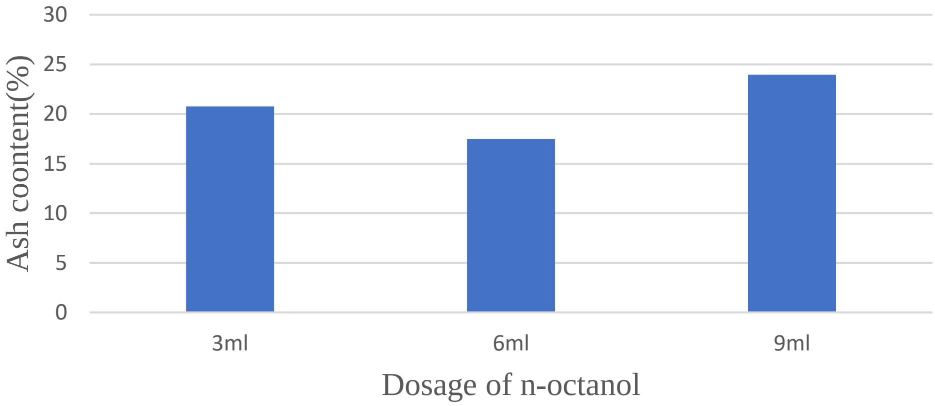

Figure 44 Shows the ash content at different frother dosage

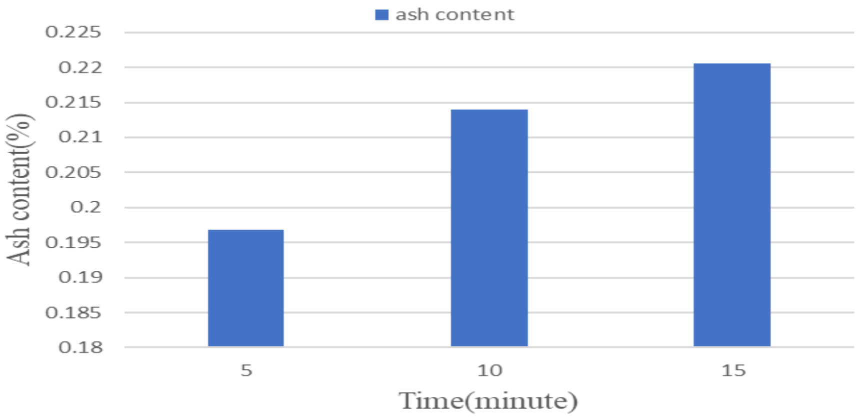

Figure 45 Shows the ash content at different flotation time

4.3.3 Volatile Matter

As can be seen the experimental results of volatile matter for the raw blended coal sample were 24.03% the higher volatile matter indicates the rank of the coal is low and increasing volatile matter indicates that increasing the amounts of combustible gases including: H_2, CO, CH4 which reduce the amount of fixed carbon content in the coal results reduce the heating value (Flotation, 2023). the current study shows reduce the volatile matter and improvement using froth flotation technique the result reduces from 24.03% to 19.29%

4.3.4 Fixed Carbon Content

The fixed carbon content of coal offers an approximate estimate of its heating value, which significantly influences the reduction of the carbon number. However, due to the high levels of ash, volatile matter, and moisture present in the coal, the fixed carbon content is lower (Flotation, 2023). The study shows improvement in carbon content of the raw blended coal is 27.63% after treated with froth flotation technique the carbon content becomes 60.06%

4.3.5 Sulfur Content

The high sulfur content in coal reduces its heating ability during combustion, primarily due to the development of high sulfur ash in the forms of barite (BaSO4), galena (PbS), and gypsum ($CaSO4 \cdot 5H_2O$). This increased sulfur leads to the release of SO_2 gas, which not only pollutes the environment but also contributes to acid rain and poses health risks, including lung cancer in humans. To address this issue, coal was beneficiated through flotation to decrease the sulfur content in the coal sample. This process enhances the calorific value and other characteristics of the coal (Turap et al., 2015). In this study the sulfur content of blended coal reduces from 0.68% to 0.44%

4.3.6 Calorific Value

The energy content of the raw and treated coal sample is determined by adiabatic boom calorimeter in the laboratory of chemical and construction inputs industry development research center as shown in the table above the obtained result of the raw blended coal sample is 4,914.73Ca/gram but after treatment the calorific value was increased. The result indicates that beneficiation by froth flotation method is appropriate approach to enhance or increase the calorific value of the blended coal. The figure (46,47 and 48) below shows the heating value of treated blended coal at different flotation parameters (particle size, frother dosage and flotation time).

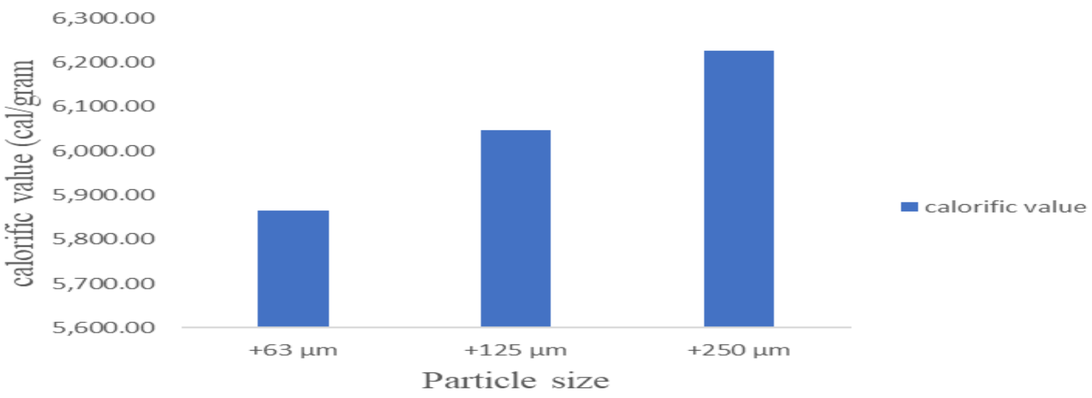

Figure 46 Shows the calorific value of treated blended coal at different particle size

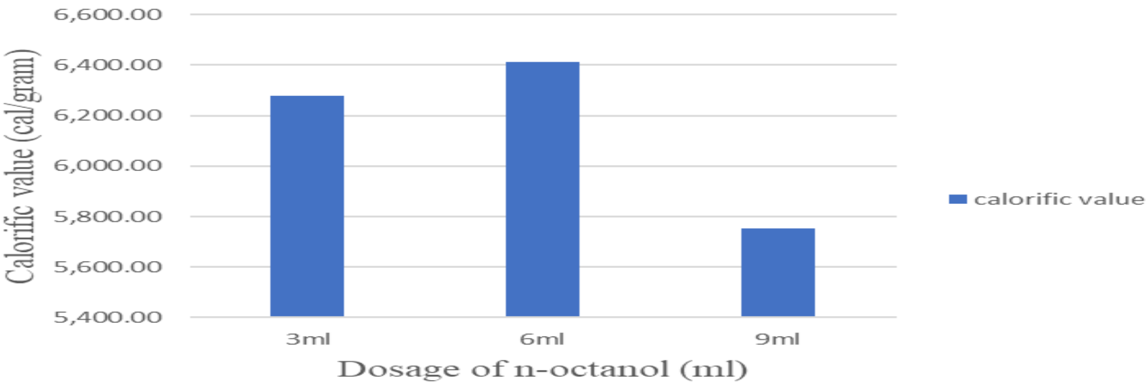

Figure 47 Shows the calorific value of treated blended coal at different frother dosage

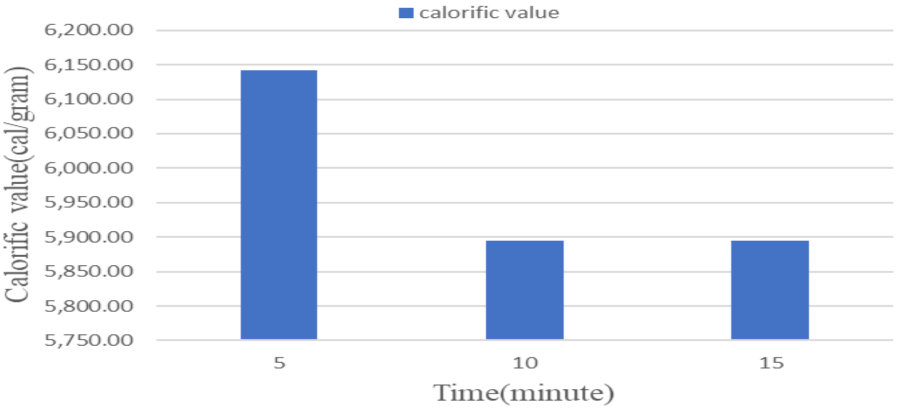

Figure 48 Shows the calorific value of blended coal at different flotation time

CHAPTER FIVE

5 Conclusions and Recommendations

5.1 Conclusions

Froth flotation affected by several operational parameters but in this project particle size, frother dosage and time is studied. The optimal particle size to get the good quality and high combustible recovery is +125+-250 µm and its Calorific value is 6,047.5781 Ca/gram. The optimal frother dosage to get maximum combustible recovery and grade is 6ml of n-octanol and its heating value is 6,412.7735Ca/gram and the optimal flotation time we get maximum recovery and quality is 10 minute its heating value is 5,894.4779Cal/gram. Beneficiation of blended coal using froth flotation technique kerosene as a collector n-octanol as frother, sodium silicate as depressant is enhance the calorific value of the raw blended coal from 4,914.73Ca/gram to 6,047.5781 Ca/gram, 6,412.7735Ca/gram, 5,894.4779Cal/gram. The result indicates improvement of the heating value of the coal in all flotation parameter of particle size, frother dosage and time respectively when you compared with the raw blended coal. Generally, froth flotation technique is good for environmentally friend method for the reduction of sulfur content in coal which reduce the release of SO_2 gas cause for the formation of acid rain and health risks including lung cancer in humans. The study reduces the sulfur content of blended coal 0.68% to 0.44%. So, the froth flotation technique is the appropriate method of removing the impurities from coal and enhancing the energy of the coal.

5.2 Recommendations

According to the finding of this study the following recommendations are suggested.

- Blending is one method of improving the heating value of coal, coast optimization, reduce environmental pollution but it does not meet the customers requirement or standard. It needs other beneficiation method like froth flotation needed to further improve the heating value and overall coal quality to meet the required standards.
- Investigating and optimizing other operational parameters like collector dosage, agitation speed, frother type and air flow rate is essential parameter for the enhancement of froth flotation technique that improves the mineral recovery, better selectivity and overall performance of the flotation process.
- Detail characterization of the physicochemical characteristics of the individual coal before blended and percentage of mixing or amount of coal reserve before blended enhance the quality of coal.
- The study shows beneficiating domestic coal is needs special attention to attract and assist potential investors in domestic coal upgrading business activities, policymakers and stakeholders should pay particular attention.
- Future researchers use the finding of this study as a reference and should study further in different coal Deposit areas by taking the sample and compare with other beneficiation method.

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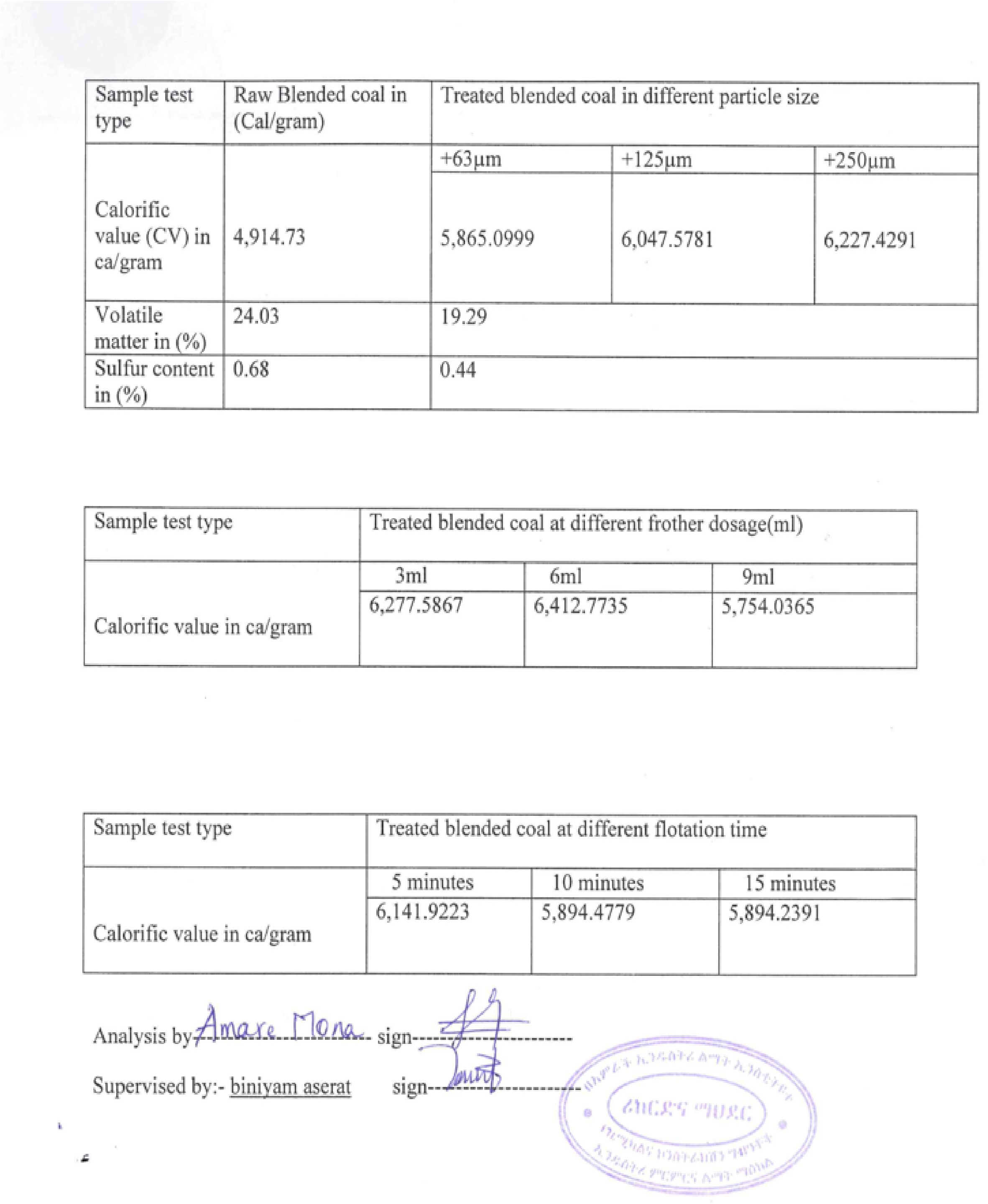
Appendix



Sample test type	Raw Blended coal in (Cal/gram)	Treated blended coal in different particle size		
		+63μm	+125μm	+250μm
Calorific value (CV) in ca/gram	4,914.73	5,865.0999	6,047.5781	6,227.4291
Volatile matter in (%)	24.03	19.29		
Sulfur content in (%)	0.68	0.44		

Sample test type	Treated blended coal at different frother dosage(ml)		
	3ml	6ml	9ml
Calorific value in ca/gram	6,277.5867	6,412.7735	5,754.0365

Sample test type	Treated blended coal at different flotation time		
	5 minutes	10 minutes	15 minutes
Calorific value in ca/gram	6,141.9223	5,894.4779	5,894.2391

Analysis by:- Amare Mona sign------------------------

Supervised by:- biniyam aserat sign------------------------

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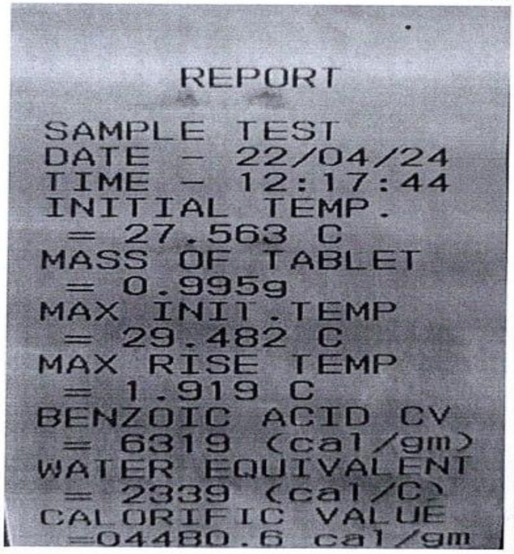

```
REPORT
SAMPLE TEST
DATE - 22/04/24
TIME - 12:17:44
INITIAL TEMP.
 = 27.563 C
MASS OF TABLET
 = 0.995g
MAX INIT.TEMP
 = 29.482 C
MAX RISE TEMP
 = 1.919 C
BENZOIC ACID CV
 = 6319 (cal/gm)
WATER EQUIVALENT
 = 2339 (cal/C)
CALORIFIC VALUE
 =04480.6 cal/gm
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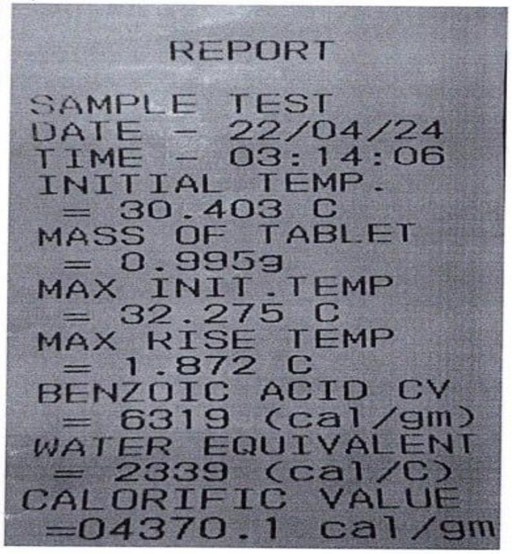

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REPORT
SAMPLE TEST
DATE - 22/04/24
TIME - 03:14:06
INITIAL TEMP.
 = 30.403 C
MASS OF TABLET
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MAX INIT.TEMP
 = 32.275 C
MAX RISE TEMP
 = 1.872 C
BENZOIC ACID CV
 = 6319 (cal/gm)
WATER EQUIVALENT
 = 2339 (cal/C)
CALORIFIC VALUE
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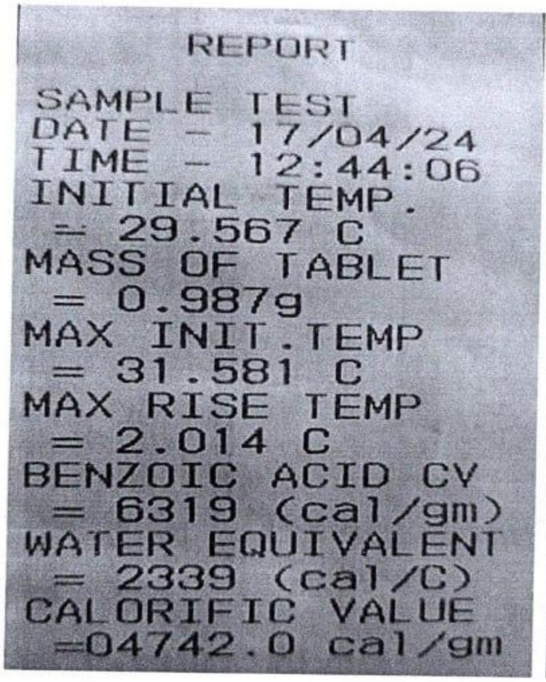

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MAX RISE TEMP
 = 2.014 C
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WATER EQUIVALENT
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CALORIFIC VALUE
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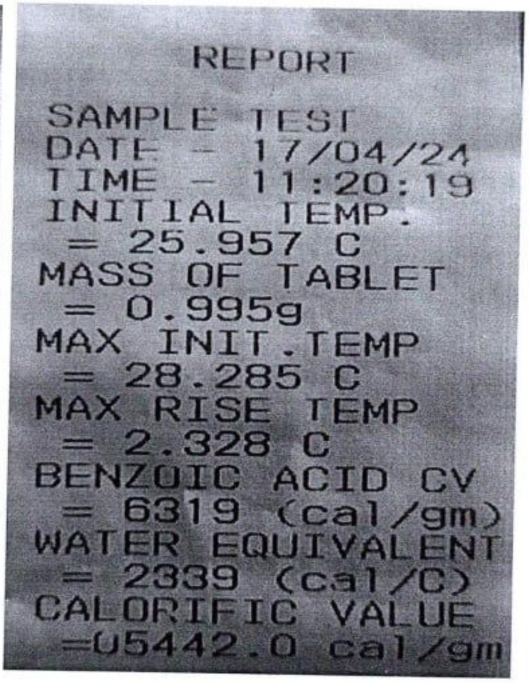

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REPORT
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DATE - 17/04/24
TIME - 11:20:19
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 = 25.957 C
MASS OF TABLET
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MAX INIT.TEMP
 = 28.285 C
MAX RISE TEMP
 = 2.328 C
BENZOIC ACID CV
 = 6319 (cal/gm)
WATER EQUIVALENT
 = 2339 (cal/C)
CALORIFIC VALUE
 =05442.0 cal/gm
```

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Flotation Experiment Data in different particle size

Flotation time (minute)	**Particle size**	***Feed (g)***	***Concentrate 1(g)***	***Concentrate 2(g)***	***Concentrate 3(g)***	***Average Concentrate taken for characterization(g)***
10	+63 µm + -125 µm	100	43.9	47.7	44.03	45.2
	+125+-250 µm	100	29.4	28.8	30.3	29.5
	+250 µm +-500 µm	100	17.9	19.6	20.4	19.3

Flotation Experiment Data in different frother dosage

Particle size	**Frother dosage(ml)**	***Feed (g)***	***Concentrate 1(g)***	***Concentrate 2(g)***	***Concentrate 3(g)***	***Average Concentrate taken for characterization(g)***
+125+-250 µm	3	100	42.7	45.8	43.2	43.9
	6	100	54.9	54.3	57.6	55.6
	9	100	44.1	47.5	44.9	45.5

Flotation Experiment Data in different flotation time

Particle size	**Flotation time (minute)**	***Feed (g)***	***Concentrate 1(g)***	***Concentrate 2(g)***	***Concentrate 3(g)***	***Average Concentrate taken for characterization(g)***
+125+-250 µm	5	100	59.02	58.1	59	58.7
	10	100	60.9	61.1	61.3	61.1
	15	100	61.9	63.1	65.5	63.5

Ash content Determination Data in different particle size

Type of sample	*Particle size*	*Crucible weight(g)*	*Weight of sample taken(g)*	*Ash with crucible(g)*	*Weight of ash(g)*	*Weight of coal(g)*
Raw		44.104	1:00	44.4221	0.3181	0.6819
Treated	+63+-125 µm	20.454	1:00	20.6534	0.1994	0.8006
	+125+-250 µm	55.429	1:00	55.6038	0.1748	0.8252
	+250+-500 µm	52.657	1:00	52.8009	0.1439	0.8561

Ash content Determination Data in Different *Frother dosage*

Type of sample	*Frother dosage*	*Crucible weight(g)*	*Weight of sample taken(g)*	*Ash with crucible(g)*	*Weight of ash(g)*	*Weight of coal*
Raw	-	44.104	1:00	44.4221	0.3181	0.6819
Treated	3ml	41.741	1:00	41.9485	0.2075	0.7925
	6ml	38.757	1:00	38.9316	0.1746	0.8254
	9ml	39.448	1:00	39.6877	0.2397	0.7603

Ash content Determination Data in Different *Flotation time*

Type of sample	*Flotation time (minute)*	*Crucible weight(g)*	*Weight of sample taken(g)*	*Ash with crucible(g)*	*Weight of ash(g)*	*Weight of coal(g)*
Raw	-	44.104	1:00	44.4221	0.3181	0.6819
Treated	5	14.762	1:00	14.9588	0.1968	0.8032
	10	35.565	1:00	35.779	0.214	0.786
	15	30.203	1:00	30.4236	0.2206	0.7794

Moisture Content of Raw and Treated Coal in different particle size

particle size	Moisture (%)	Type of sample
-	15.85	Raw coal
+63+-125 µm	4.922	Treated coal
+125+-250 µm	1.720	Treated coal
+250+-500 µm	1.633	Treated coal

Moisture Content of Raw and Treated Coal in different frother dosage

Frother dosage	Moisture (%)	Type of sample
-	15.85	Raw coal
3ml	3.17	Treated coal
6ml	2.750	Treated coal
9ml	3.27	Treated coal

Moisture Content of Raw and Treated Coal in different flotation time

Flotation time(minute)	Moisture (%)	Type of sample
-	15.85	Raw coal
5	1.38	Treated coal
10	3.068	Treated coal
15	3.179	Treated coal