ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

CENTER FOR ETHIO-MINES DEVELOPMENT (CEMD)

MASTER OF ENGINEERING IN MINERAL ENGINEERING

EFFECTES OF SINGLE AND MIXED COLLECTORS IN LOW-GRADE COAL FLOTATION: THE CASE OF GAMO GOFA ZONE, SOUTHERN ETHIOPIA

CENTER FOR ETHIO-MINES DEVELOPMENT, ADDIS ABABA INSTITUTE OF TECHNOLOGY, ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF ENGINEERING IN MINERAL PROCESS ENGINEERING

BY

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DECLARATION

Desta Mulugeta (GSR/5990/15), Hereby Decler that this MSC Research Project Entitled "***EFFECTES OF SINGLE AND MIXED COLLECTORS IN LOW GRADE COAL FLOTATION; THE CASE OF GAMO ZONE COAL IN SOUTHERN ETHIOPIA***." Has Been Developed By Me And Has Not Been Submitted To Any Other Institution For The Purpose Of Obtaining Any Academic Qualification. I Confirm That The Content Is Original And Free From Plagiarism, And All References To The Work Of Other Researchers Have Been Properly Cited.

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

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Approval Page

This to Confirm That We have Reviewed the MSc Research Project and, In Our Assessment, It Meets the Necessary Standards of Scope and Quality Expected for a Master's Research Project for the Degree of Master of Engineering in Mineral Engineering.

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List of Abbreviation and Units

- AAiT ……………………… Addis Ababa Institute of Technology
- ASTM ………………………American Society for Testing Materials
- CEMD …………………… Center for Ethio Mines Development
- g …………………………… gram
- LRC……………………….. Low Rank Coal
- ml ………………………... mili-liter
- MSc ……………………… Masters of Science
- Rpm ………………………… Revolution per minute
- ℃ ………………………….. Celsius scale
- µm ………………………….. micro meter

Abstract

This study investigated the effectiveness of single and mixed collectors in enhancing the flotation efficiency of low-grade coal from the Gamo Gofa Zone of Southern Ethiopia. The research aimed to address the challenges posed by high ash content and impurities in Ethiopian coal, which limit the industrial application. Through controlled laboratory experiments, the performance of single collectors (kerosene, diesel oil, and oleic acid) and mixed collectors in varying dosages was evaluated. The Finding revealed distinct performance characteristics among the collectors. Kerosene demonstrated higher recovery rates (33.7%) but moderate ash content (27.2%), while oleic acid prioritized purity (lowest ash content of 24.9%) at the expense of recovery (27.3%). Diesel oil showed intermediate results. Mixed collector formulations further highlighted the trade-off between recovery and ash content. For instance, the balanced triple-mixed collector C13 (kerosene, oleic acid, and diesel oil in equal parts) achieved a competitive recovery rate of 55.2% with acceptable ash levels (33.7%). In contrast, formulations with higher oleic acid content (C11) yielded the lowest ash content (32%) but reduced recovery (44%). The study underscored the inverse relationship between recovery and ash content, emphasizing the need for tailored collector blends based on specific industrial priorities. For yield-focused processes, Equal-dose blends like C10 (56.3% recovery) are recommended, while purity-focused applications benefit from oleic acid-dominant mixtures like C11. The balanced C13 formulation emerged as a practical choice for scenarios requiring a middle ground.

Keywords: Single collector, Mixed collector, Floatation, Coal, Ash content, Grade, Coal recovery.

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Energy serves as a fundamental resource for economic growth and human existence. It is essential across various sectors including industry, agriculture, mining, construction, and service-oriented organizations. The continuous rise in petroleum prices impacts nations globally. In light of the current global energy crisis, lower-quality fuels such as coal, oil shale, and tar sands are emerging as alternative resources in numerous countries. Many nations are initiating the development of diverse coal fields (Wolela 2007).

In response to the increasing energy demands in Ethiopia, ongoing research is being conducted across multiple sectors to develop hydroelectric power plants, geothermal energy sources, natural hydrocarbons, solar energy, and more. The primary energy sources in Ethiopia include wood, oil, and hydroelectric power, which serve the domestic, industrial, and transportation sectors(Tadesse *et al.,* 2003). A significant portion of the rural population, along with many urban residents, relies on wood as their main source of domestic fuel. This reliance on wood for fuel is a key driver of deforestation in Ethiopia, leading to serious environmental issues such as soil degradation, desertification, and the destruction of natural ecosystems.

According to (Dwari et al., 2007), coal continues to play a major role in the economic development of a country, especially in metallurgical industries and conventional power generation plants. For effective utilization of high ash coals, it is necessary to beneficiate properly(Dwari and Rao 2007).

It is known that coal is the primary fossil fuel and supplies approximately 42% of the electricity to the world (Zhu et al., 2019); it will still hold a dominant position in the energy supply until 2050 (Demirbas 2007). Coal is the main fossil fuel in many countries, accounting for almost 70% of the primary energy consumption especially in China(Xing et al., 2017). Nearly half of all global coal deposits are low-rank coals including sub bituminous coal and lignite, which are very abundant in China, Australia, Turkey, India, and the northern US(Li et al., 2014).

Owing to advances in energy conversion technologies, which allow the production of a large variety of end products from different feed stocks, the world oil, gas and coal markets are becoming increasingly inter-related. The energy market of the future will thus tend to become a market for hydrocarbons rather than one differentiated by energy sources. This is expected to have important implications for coal supply and demand patterns in the future (Kavalov and Peteves 2007)

Coal mining not only produces, but also consumes a large amount of energy. Coal production has an extremely high energy efficiency potential, and benchmarking is critical to discover this potential. Research on energy efficiency in the coal industry primarily focuses on coal processing and utilization, including power generation, chemical, metal smelting other key industries (Crossley 2020).

Statistics show that over 30 billion metric tons of coals are available in the top 10 coal producing countries owing to the difficulties associated with the treatment of coal fines. These coal fines are disposed and left on either stock piles and slurry ponds near mining sites or added in steam coal regardless of the fact that they constitute a high potential source of energy (Ramudzwagi et al., 2020).

Flotation is the main method for recovering and reusing fine low-rank coal by taking advantage of the difference in physicochemical properties of the mineral surface, but its efficiency has not yet reached a satisfactory level. Particles, flotation reagents, and air bubbles are highly dispersed and interact with each other in a flotation cell.

Separating combustible matter from mineral-formed ash has an important role in improving the calorific value and utilization efficiency of fine coal (Xing *et al.,* 2017). Flotation method is the most effective for fine coal beneficiation. Conventional oily collectors, such as diesel oil, kerosene, and fuel oil, are widely used as flotation collectors to improve the floatability of coal. However, for low-rank coal, traditional collectors cannot be effectively adsorbed on its surface because of the existence of hydrophilic oxygenated functional groups.

Therefore, a basic understanding on the fundamental mechanism of the above interactions involved in a low-rank coal flotation system is the prerequisite for improving low-rank coal flotation recovery (Xia et al., 2020). The efficient flotation separation of low-grade coal is still a difficult problem. The development of a collector is the key to solve the problem(Kang and Zhang 2022). As a result, this project mainly focuses on the Effectiveness of Single and Mixed Collectors with collector Dosage in Low Grade Coal Flotation in Gamo Zone, Southern Ethiopia.

1.2 Description of the Study Area

The Urgoye coal mining company is situated in the Gamo Gofa Zone of southern Ethiopia. Coal extraction occurs in the Kucha Wereda, which is part of the broader Gamo Gofa zone. Kucha is one of the Woredas located within the Gamo Gofa Zone. It lies between the latitudes of 6° 32' N and 6° 30' N, and the longitudes of 37° 17' E and 37° 40' E. The region is bordered to the north by Ofa Wereda of the Wolayta Zone, to the northwest by Loma Bossa of the Dawro Zone, to the east by Boreda and Chencha Woreda, to the south by Daramallo Wereda, and to the west by Zalla and Goffa Zuria Woreda (Endale, et.al 2003). Kucha Wereda, located in the Gamo Gofa Zone of Ethiopia, possesses substantial coal reserves, estimated at 744,174.96 tons according to pit logs, geophysical data, and surface area assessments. The coal in this region is currently being mined, mainly to meet the demands of cement manufacturers, and is drawing interest from various companies for exploration and mining ventures.

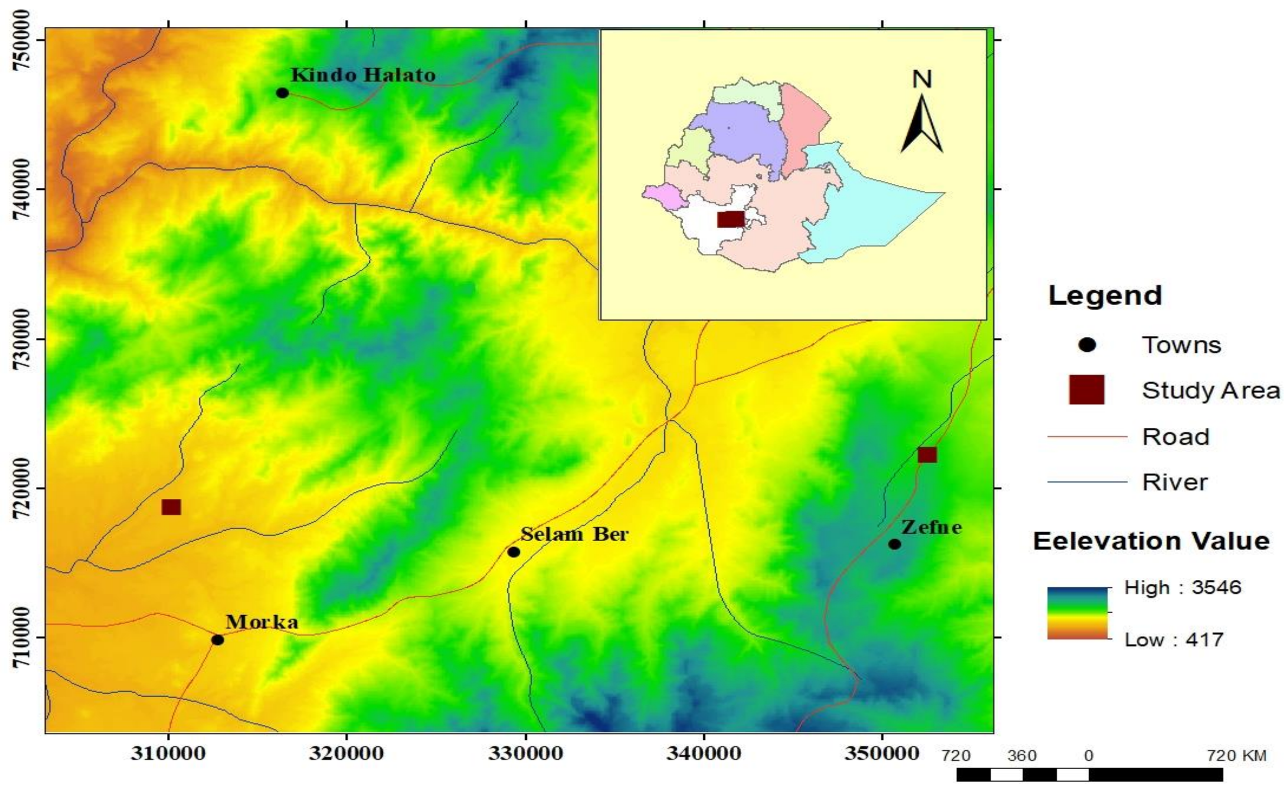

Figure 1. 1 Location of the Study Area.

1.3 Geology of the Study Area

1.3.1 Lacustrine, volcano clastic sediments and tuffs (Qvs)

The northern portion of the Geological map shows this lithological unit. The lacustrine and volcanoclastic sediments are often pale yellow in color and medium in particle size. Aphyric and scoraceous basalts, ignimbrites, unwelded tuffs, volcanic sediments, and lacustrine sediments are among the rock formations. Tuffs and volcanic deposits make up the majority of the exposures. The light gray, friable, and 20-meter-thickness volcanoclastic deposits are their defining characteristics.(Zenebe et al. 2016).

1.3.2 Lower basalt, aphyric to porphyritic rhyolites and trachyte's (Tv1)

Small amounts of this earlier volcanic unit may be found in the map sheet's southern east and west regions. The thick, widespread lava flows that exhibit columnar jointing and significant weathering locally are characteristics of the Lower Basalt. In the Lower Basalt, the textures of the several flows vary significantly. This is intercalated with olivine-plag phyric basalt, rhyolites, and ignimbrites(Aman Yismaw, et al 2015).

1.3.3 Nazreth Group and Dino Formation (Tig1)

This unit covers a large portion of the map, particularly the study area. It includes a variety of lithounits, including tuffs, rhyolites, basalts, and ignimbrites. These many unit types represent the upper Miocene exposure governed by a few key features with a northeastern tendency. The weathered hue of this lithic fresh ignimbrite is light brown, and it exhibits a light gray to gray tone(Aman Yismaw, Bezayit Mitiku 2015).

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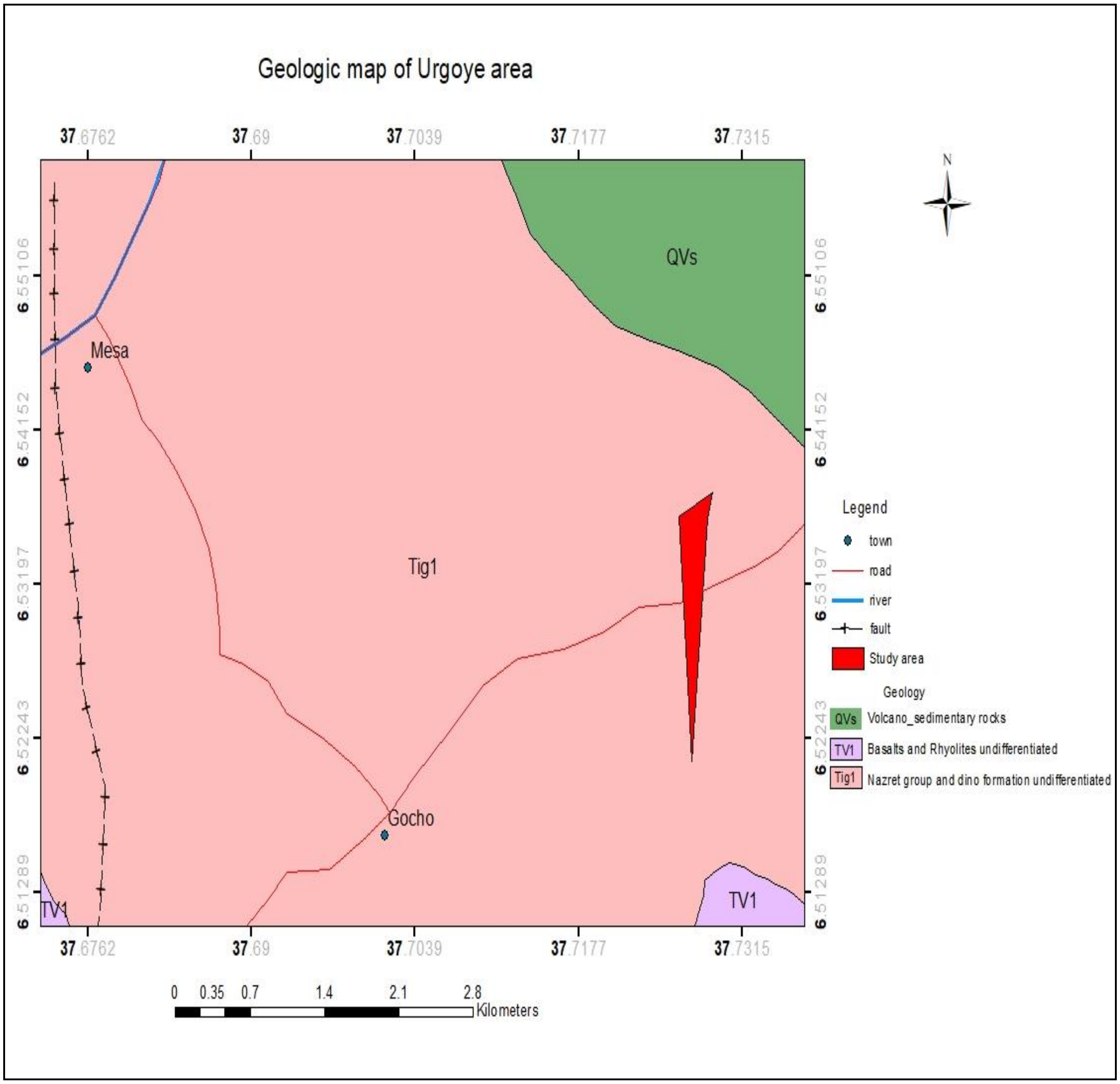

Figure 1. 2 Geological map of the study area.

1.4 Statement of the Problem

Coal continues to be a vital energy source in Ethiopia and globally. However, the presence of high ash content, moisture, and other impurities in these low-grade coals significantly restricts their direct application in industrial settings. Flotation has been recognized as an effective technique for enhancing low-grade coal, but its effectiveness is largely influenced by the type and amount of flotation reagents used, especially collectors. Despite advancements in flotation reagent technology worldwide, there is a scarcity of research and practical data regarding the efficacy of single versus mixed collectors in the beneficiation of Ethiopian coal. Additionally, the ideal dosage levels for optimizing recovery while reducing ash content are still largely unknown for the unique coal characteristics found in the Gamo Gofa Zone This lack of information results in inefficient coal beneficiation practices in the area, leading to underutilization of resources and increased processing costs. Therefore, it is crucial to assess the performance of both single and mixed collectors at different dosages to determine the most effective and cost-efficient flotation conditions for enhancing the quality of low-grade coal in Gamo Gofa Southern Ethiopia.

1.5 Research question

- What are the comparative effects of single collectors versus mixed collectors on the flotation efficiency of low-grade coal, specifically in terms of recovery rates and ash content?
- How do know the impact of varying molar ratio of mixed collectors affect the quality of the coal during floatation processes?
- What optimal ratios of mixed collector components yield the highest flotation efficiency for low-grade coal, and how do these ratios influence the physicochemical properties of the coal surface?

1.6 Objective of the study

1.6.1 General objective

To evaluate and compare the effectiveness of single and mixed collectors.

1.6.2 Specific objective

- To evaluate the flotation recovery rates of low-grade coal using single collectors and compared to mixed collectors under controlled laboratory conditions.
- To analyze the impact of varying molar ratios of mixed collectors on the ash content and overall quality of the coal produced during flotation processes.
- To identify the optimal dosages of single and mixed collectors that maximizes the recovery and yield of coal particles during the flotation process.
- In enhancing the flotation efficiency of low-grade coal, focusing on recovery rates, and ash content.

1.7 Scope of the study

The effectiveness of single and mixed collectors in low-grade coal flotation lies in its potential to enhance the efficiency of coal beneficiation processes. Low-grade coals often possess high moisture and ash content, making them less desirable as energy sources. Hence the scope of this project is to improve the recovery and quality of coal, by optimizing flotation techniques. This study thoroughly examine how well single and mixed collectors work in the process of floating low-quality coal. In the project activity the effect of collector mixture on the recovery rate and decreasing the ash content was investigated.

1.8 Significance of the study

This study provides crucial insights into improving coal flotation techniques in Gamo, Ethiopia, with the goal of boosting recovery rates for low-grade coal. Furthermore, identifying the most effective type of collector, whether single or mixed, along with the optimal dosage, can lead to lower reagent costs and improved flotation efficiency, yielding economic advantages for mining companies. By refining collector usage, the research also seeks to minimize chemical waste and reduce the environmental impact of coal processing. This work adds to the current understanding of flotation techniques, particularly for low-grade coal, a subject that has not been extensively explored in Ethiopia. The findings may serve as a basis for future research on mixed collector systems in mineral processing.

The findings can also help industry executives and policymakers adopt best practices for coal beneficiation, which could impact investment choices in Ethiopia's mining sector by emphasizing successful coal improvement initiatives.

1.9 Limitation of the study

Assessing the Effectiveness of Single and Mixed Collectors in the Flotation of Low Grade Coal conducted in the Gamo region of Southern Ethiopia (URGOYE COAL MINING) reveals several constraints that could influence the interpretation and relevance of its conclusions. To begin with, the study focused on a particular coal deposit in the Gamo zone, which might not be representative of other coal deposits either in Ethiopia or worldwide, thereby limiting the broad applicability of the findings. The flotation tests were carried out in a controlled lab setting using a 3-liter batch flotation apparatus, which may not accurately depict the complexities and dynamics experienced in industrial-scale operations. Furthermore, the research mainly relied on Kerosene, Diesel oil, Oleic acid as a collectors and Pine oil as a frother; the efficacy of these reagents could differ based on various coal types or impurities, narrowing the significance of the results in other scenarios. Different type and dosages of collectors were investigated, but other significant factors like pH levels, temperature fluctuations, and supplementary reagents were disregarded. This omission could impede the optimization of flotation efficiency. The emphasis on yield and recovery metrics also fails to take into account essential aspects such as the environmental effects of chemical usage and the long-term stability of performance under diverse operational conditions.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Principle of Coal Formation

Coal is a type of fossil fuel formed from the decomposition of organic materials. While the fundamental process of coal formation remains consistent, there are slight regional differences influenced by vegetation and environmental conditions. The conversion of plant matter into peat and subsequently into coal is typically viewed as occurring in two stages, known as the biochemical and physicochemical stages(State and Academy 2025). The formation of coal involves two primary phases: peatification and coalification.

2.1.1 Peatification:

When Plant matter in swamps and wetlands, such as ferns, shrubs, vines, trees, and algae dies and accumulates on the surface. Initially, the organic matter is decomposed by bacteria, yielding carbon dioxide and methane. The plant matter becomes buried and is no longer exposed to air. Anaerobic bacteria then start to decompose the material. Burial and accumulation occur for several thousands of years, producing several meters of partially decayed plant matter known as peat(Chinweze et al. 2023a).

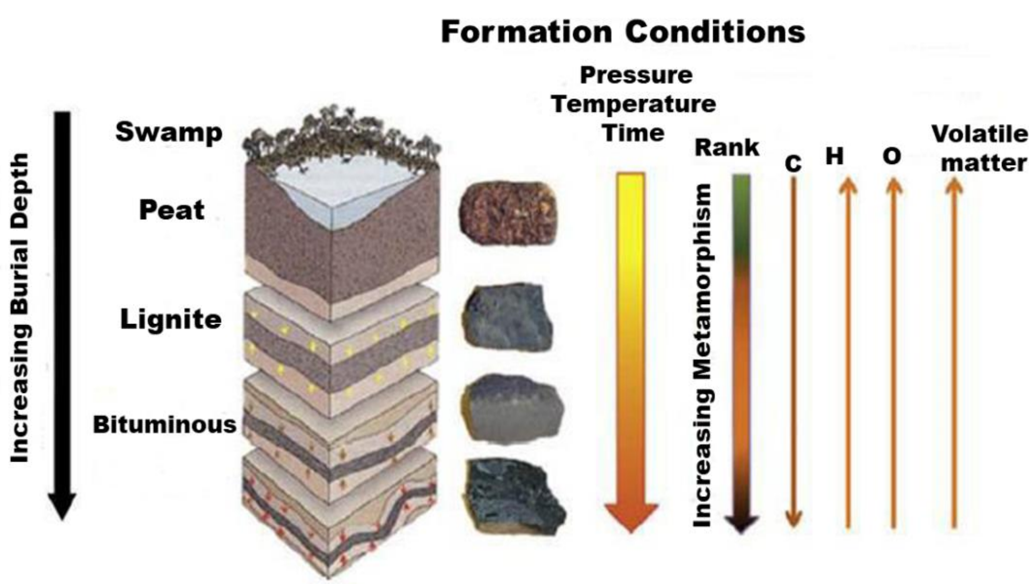

Figure 2. 1 Scheme of the formation of coal in terms of rank (Chinweze et al. 2023a).

2.1.2 Coalification

Coalification occurs due to the temperature and pressure associated with burial, and is further influenced by geological time and tectonic activity. The processes involved in coalification include dehydration, bituminization, debituminization, and graphitization, which entail both chemical and physical alterations of organic material. As peat is subjected to deeper burial, water and various compounds are expelled due to the rising pressure, leading to the formation of lignite, the lowest grade of coal (Thakur 2020).

Continued burial, accompanied by escalating pressures and temperatures, facilitates the transformation of this low-grade lignite into higher-grade 'black coals'. Initially, lignite evolves into sub-bituminous coal, followed by bituminous coal, and ultimately the highest grade, anthracite coal. Throughout these transformations, the water content and other compounds within the coal diminish, resulting in increased density and a higher concentration of carbon (Chinweze et al., 2023b).

In general, the extent of transformation, referred as the 'rank' of coal, describes the progression from peat to anthracite. Low-rank coals, such as lignite and sub-bituminous coals possess lower energy content due to their reduced carbon levels. Nevertheless, when discussing low-grade coal, the concept of rank becomes less significant. Although there is no universally accepted definition for low-grade coal, it can be characterized as coal with limited utility due to unfavorable traits, such as high mineral matter content. All low-rank coals, including sub-bituminous and brown coal, are typically classified as low-grade due to their elevated moisture levels and low heating values, necessitating specialized technologies for their use in power generation (Katalambula and Gupta 2009).

2.3 Basics in Coal Flotation

Coal flotation is a very complex process that is characterized by a large variation in physical and chemical properties of treated material, i.e. coal and mineral matter (Sokolovic and Miskovic 2018). The different phases interact with one another as well as with other substances, such as dissolved ions in water and reagent molecules. These chemical and physical interactions influence the flotation process's results. Notably, aggregation which is especially frequent in high-rank coals can result via interactions between tiny coal particles. The problems with selectivity in coal flotation are largely caused by this non-selective particle aggregation.(Polat and Chander 2003).

In the case of coal, flotation is by far the most commonly used beneficiation method in the finer sized range. Coal because of its natural hydrophobicity is collected in the froth while mineral gangues remain in the pulp as tailings (Jaiswal,et.al 2015). There are several research articles published on flotation of coal and its allied research topics covering both basic science as well as on applied research. The idea of reverse flotation for coal started with the first patent done by Eveson in 1961(Shen and Wang 2016) on bituminous coal in which shale i.e. the mineral matter was floated and reported in the froth phase while the clean coal was depressed and remained in the suspension. Consequently the study of reverse flotation of coal with a motive to lower the ash content of coal was carried out by many scientists and researchers.

2.4 Collector Types and Mechanisms

A very effective method for separating fine coal is froth flotation, which takes advantage of the differences in surface hydrophobicity between organic and mineral components. The upgrading process takes advantage of these variations in hydrophobicity(Gui et al., 2017; Xing et al., 2016). The most common collectors used in the industrial coal flotation process are non-polar hydrocarbon oils like diesel or kerosene. The main way that these oils stick to the coal surface is through hydrophobic interactions. However, Low Rank Coal (LRC) finds it difficult to interact with these hydrophobic hydrocarbon oils because of its stronger hydrophilic properties. Furthermore, hydrocarbon oil-based collectors exhibit poor dispersion in coal flotation systems, which causes oil droplets to clump together and raise consumption rates while decreasing flotation efficiency (Wang et al., 2025).

Flotation serves as a highly effective technique for the separation and enhancement of fine coal slime. In the context of low-rank coal (LRC) flotation, the choice of an effective collector is essential for optimizing flotation performance. Recent research indicates that compound collectors, which consist of both polar and nonpolar components, demonstrate superior flotation efficiency at a reduced cost, making them a focal point of investigation in LRC flotation studies (Yao et al., 2021).

CHAPTER THREE

3. MATERIALS AND METHODOLOGY

3.1 Raw Material

Approximately 5 kilograms of Gamo coal sample, obtained from the open pit mine operated by URGOYE COAL MINING, was utilized in this study. To achieve size reduction, a jaw crusher and pulverizer were employed, along with a centrifugal mill. Subsequently, samples of varying grain sizes were separated using a sieve shaker with a sieve size of 250µm-100µm. additionally, flotation processes were conducted using a flotation cell, with kerosene, oleic acid, and diesel oil serving as collectors. A drying oven was utilized for the drying process.

3.2 Lab Equipment

The basic lab Equipment’s that used to conduct the study was lumps of coal which was obtained from Gamo Gofa Zone of Southern Ethiopia and the equipment's that were used for this work includes; laboratory jaw crusher (RoHs53743) Figure 3.1 A, Centrifugal milling machine (Figure 3.1 B), sieves with different mesh sizes (Figure 3.1 C) ,laboratory wedge flotation cell (Groppel 98) Figure3.1 D, Oven(Figure 3.1 E) ,and Furnace (Figure3.1 F)

Figure 3. 1 Laboratory equipment used in this project.

3.3 Sample Preparation

The coal sample was first crushed using a jaw crusher, followed by pulverization into fine particles. This crushed material underwent centrifugal milling, and the resulting milled coal was sorted by size with a sieve shaker featuring a 250 µm mesh.

For the flotation experiment, a total of 16 samples were prepared, each weighing 100 grams. This meticulous preparation ensured that the samples were uniform and suitable for the intended analysis.

3.4 Flotation Processes

Flotation Cell Configuration: In each experiment, 100 grams of the sample were combined with 2 liters of tap water and agitated for three minutes at both high and low impeller speeds, ensuring that the coal particles were thoroughly wetted by sealing the air valve with tape. Subsequently, each of the 16 samples was treated with three different dosages of collectors: 2 ml, 2.5 ml, and 3 ml, along with 2 ml of pine oil frother for each collector dosage, and agitated for an additional three minutes. During this process, the air valve was opened to introduce air into the flotation cell, facilitating the formation of bubble particles. This bubble formation continued until the cell overflowed, at which point the bubbles were collected. The collection and foam generation persisted until foam was visible, signifying that all solid particles within the cell had adhered to the kerosene, oleic acid, and diesel oil collectors(Kang and Zhang 2022).

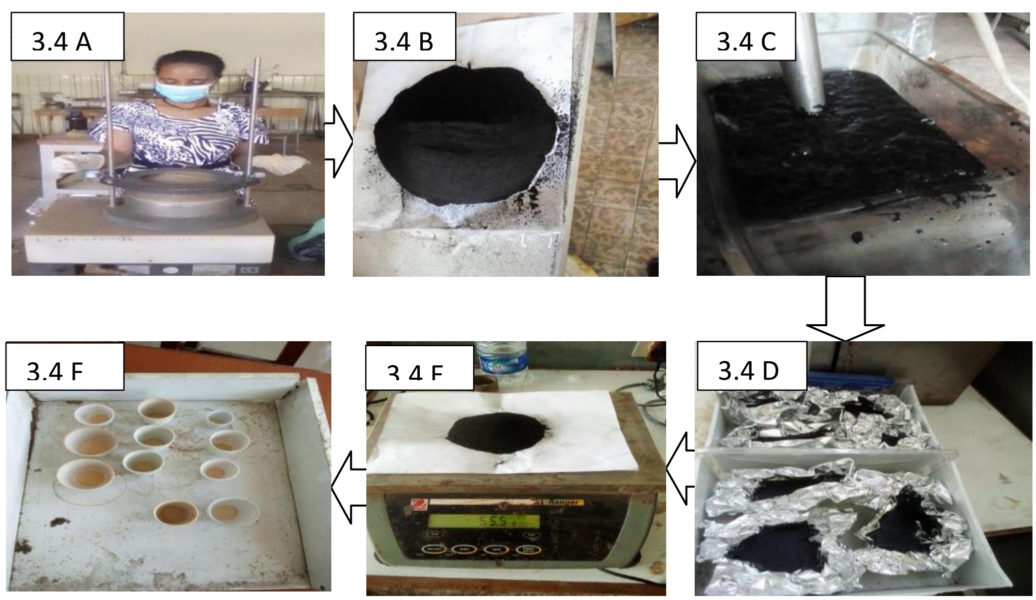

Figure 3. 2 Steps used in the flotation processes.

3.5 Experimental Design

Samples were grouped in to 16 each having 100gm and the samples were subjected to floatation with single and mixed collectors having different dosages, and samples were coded with different letter. Moreover flotation process runs for 10 minutes with flotation machine Impeller speed of 1850rpm at room temperature and neutral (PH 7) value. Finally the yield was calculated using the equation provided below for each experimental run conducted (Journal et al. 2020)

$$Yield\ \% = \frac{Mass\ of\ Concentration}{Mass\ of\ Feed} x100 \quad \ldots\ldots\ldots\ldots.. \quad [3.1]$$

To assess the ash content in coal, the ASTM D3174 method was employed, which involves burning a coal sample under regulated conditions. The procedure starts with placing the coal sample in a crucible, which is subsequently heated in a muffle furnace at a specific temperature of 750°C for eight hours. Throughout this period, the organic materials in the coal are burned off, resulting in inorganic residues referred to as ash. Once the combustion is finished, the residual ash is meticulously weighed, and its mass is calculated as a percentage of the initial weight of the coal sample.

$$Ash\ (\%) = \frac{Weight\ of\ Residual\ left\ after\ burning\ (g)}{Weight\ of\ Feed\ Coal\ (g)} x100 \quad \ldots\ldots\ldots\ldots..[3.2]$$

The ash percentage for each sample is calculated using a designated formula shown in equation 3.2, which guarantees an accurate depiction of the ash content in relation to the original sample weight. This approach offers a dependable evaluation of the mineral content in coal, essential for numerous applications within the energy industry.

$$Recovery = \frac{Mass\ of\ Valuable\ minerals\ in\ concentrate}{Mass\ of\ Valuable\ minerals\ in\ the\ feed} x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[3.3]$$

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.

$$Grade = \frac{mass\ of\ valuble\ component}{total\ mass\ of\ the\ ore} x100 \text{ ………….. [3.4]}$$

In mineral processing, the term "grade" typically refers to the concentration of valuable minerals or metals in an ore. The grade is expressed as a percentage or a ratio of the valuable component to the total mass of the ore.

CHAPTER FOUR

4. RESULT AND DISCUSSION

The experiments aimed to determine how individual and combined collectors affected two critical parameters: yield % and ash content, as well as the flotation process's overall effectiveness. Ash content shows that there are still undesirable components present after separation, but yield % shows how much valuable material was successfully extracted. In order to fully evaluate these variables, the experiments used a single collector for comparison and methodically changed the dosage of mixed collectors from zero to three milliliters. A thorough grasp of how different collector types and their concentrations affect the flotation process's outcomes was made possible by this methodology. Throughout the research procedure, all parameters, including pH, frothers, and particle size, were maintained constant to guarantee accurate results.

While keeping the type and dosage of frother constant throughout the studies, the main focus of the research was on the effects of both single and mixed collectors. By investigating the effects of different combinations of collector doses on the flotation process, the researcher was able to get important insights into the connection between these amounts and the final results. The goal of the study was to ascertain how these variables interact within the process by systematically varying the collector doses and assessing their combined impact on flotation efficiency..

The findings of the experiments are particularly noteworthy, as they highlight two critical metrics: the yield percentage and the ash content of the final product. The yield percentage serves as an indicator of the amount of valuable material successfully recovered during flotation, while the ash content reflects the level of undesirable minerals present in the end product. These results not only underscore the importance of optimizing collector combinations but also offer valuable guidance for improving the overall quality of the flotation process. The comprehensive results of these experiments were discussed in greater detail in the subsequent sections.

4.1 Effects of Single collector on Yield Percentage & Ash Content

The yield percentage Ash content, influenced by single Collector having the same dosage, was analyzed, with the findings presented in Table 4.1.

Table 4. 1: Coal Flotation Test Result for single collector with same dosage**.**

Sample code	Type of single collector	Collector dosage (ml)	Weight of raw coal sample <250µm screen	Weight of dry concentrate sample (g)	Weight of concentrate taken for combustion (g)	Weight of coal in the concentrate (g)	Ash content
D1	Kerosene	3ml	100g	28	0.9896	0.7201	0.2695
D2	Diesel oil	3ml	100g	22.2	0.9608	0.7213	0.2395
D3	Oleic acid	3ml	100g	27.3	0.9804	0.6709	0.3095

Table 4.1 illustrates that the same amount of coal sample were used in different collector having same doses. In the processes different amount of coal concentrates as well as ash content were investigated. The result In Table 4.1 confirmed that it was found more concentrate (0.7213g) when the coal sample is subject to diesel oil while it has leas concentrate (0.6709g) in the case of oleic acid.

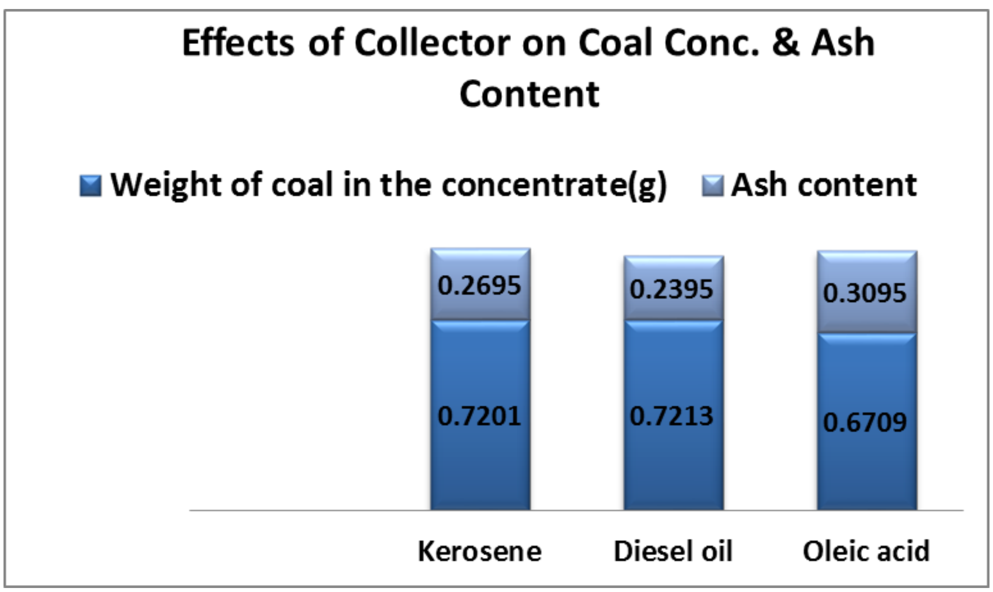

Figure 4. 1: Effects of Single Collector on Coal Concentration and Ash Content

Using a similar methodology, Figure 4.1 shows that the ash content increases(0.3095) while the coal concentrate decreases (0.6709g) when oleic acid is used, whereas the lowest ash content (0.2395) and the highest coal concentrate were observed (0.7213g) with diesel oil.

4.2 Recovery Rate of Coal and Ash content in Single Collector

To study the actual recovery and ash content relation of the coal extracted by those single collectors, the data were used and the results were calculated using equation 3.1,3.2,3.3 and 3.4 and the results were presented in the table 4.2 below.

Table 4. 2: Effects of single collector on coal recovery and Ash content

Sample code	Type of single collector with the same dosage	Coal flotation concentrate				Recovery (%)	Grade (%)
		Combustible matter /coal content (%)	Ash content (%)	Amount of coal in the concentrate(g)	Amount of ash in the concentrate(g)		
D1	Kerosene	72.8%	27.2%	20.38	7.6	33.7%	72.8%
D2	Diesel oil	75.1%	24.9%	16.67	5.5	27.3%	75.1%
D3	Oleic acid	68.4%	31.6%	18.67	8.6	30.5%	68.4%

Unlike the above concentration of coal, the recovery percentage shows the highest in the case of using Kerosene as collector (33.7%), but the ash content percentage is medium (24.9%). Whereas the least recovery percentage was registered when the collector was Diesel oil (27.3%), but is has least ash content (24.9%).

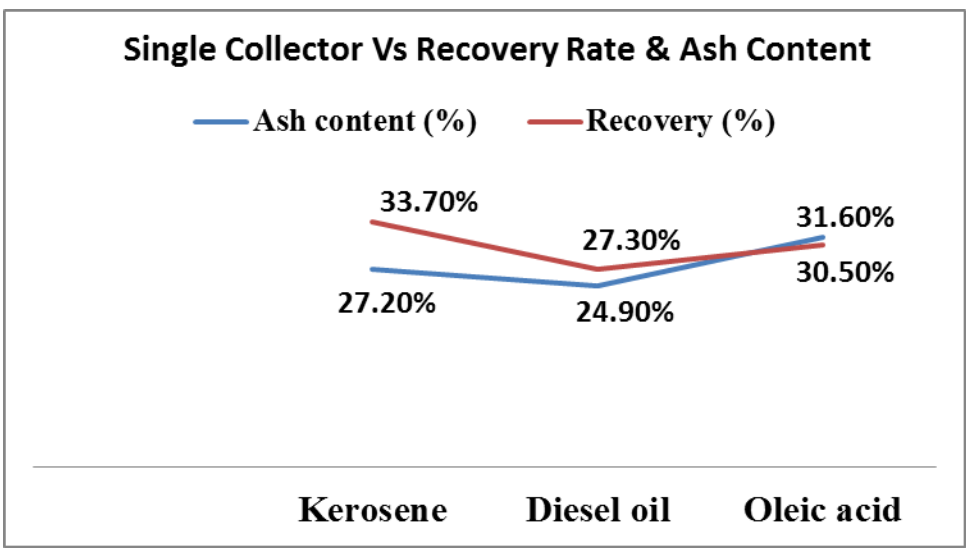

Figure 4. 2: The effects of single collector on the recovery rate & ash content

In a manner similar to table 4.2, figure 4.2 illustrates that employing diesel oil as the sole collector results in lower coal recovery and a higher percentage of ash content. Conversely, kerosene, which has a moderate ash concentration, yielded a superior recovery rate. Meanwhile, oleic acid, despite having the highest ash content, achieved an average coal recovery rate.

4.3 Effects of Mixed Collector on Recovery Rate and ash Contents

The study was segmented into three parts. The initial part featured two collectors in equal amounts simultaneously, resulting in three experiments. The second part comprised six experiments that involved two collectors with different dosage combinations (3 ml: 2 ml). The final part included four tests utilizing three collectors with varying dosage ratios.

4.3.1 Effect Two Collectors with Similar Ratio as Mixed Collector

The selected sample collectors were treated by mixing two collectors at once with an equal dosage of 2ml each simultaneously to investigate the recovery property. Following the recovery processes, the impact of the combined collectors was examined, and the findings are presented in Table 4.3 below.

Table 4. 3: Coal Flotation Test Result for double collector with same dosage.

Sample code	**Type of double collector with same dosage**	**Collector dosage (ml)**	**Weight of raw coal sample <250μm screen**	**Weight of dry concentrate sample (g)**	**Weight of concentrate taken for combustion (g)**	**Weight of coal in the concentrate(g)**	**Ash content**
C1	Kerosene Oleic acid	2ml 2ml	100g	45.7	1.0025	0.6995	0.303
C2	Oleic acid Diesel oil	2ml 2ml	100g	39.6	1.0036	0.7239	0.2797
C3	Kerosene Diesel oil	2ml 2ml	100g	43.3	1.052	0.7678	0.2842

In Table 4.3, the weight of coal in the concentrate appears to be higher when using a mixed collector that combines kerosene and diesel oil.

Conversely, the ash content is lowest in the mixed collector that utilizes oleic acid and diesel oil. Additionally, the weight of coal in the concentrate is minimized in the mixed collector when kerosene and oleic acid are combined.

To investigate the percentage of coal recovery and ash content the numerical values were analyzed using equation 3.1 and 3.2 and results were shown in table 4.4 below

Table 4. 4: Effects of Mixed Collector (with equal pof doses) on coal recovery and Ash content

Sample code	Type of double collector with the d/t dosage	Coal flotation concentrate				Recovery (%)	Grade (%)
		Combustible matter /coal content (%)	Ash content (%)	Amount of coal in the concentrate (g)	Amount of ash in the concentrate (g)		
C1	Kerosene Oleic acid	69.8%	30.2%	31.9	13.8	52.2%	69.8%
C2	Oleic acid Diesel oil	72.1%	27.9%	28.6	11	46.8%	72.1%
C3	Kerosene Diesel oil	73%	27%	31.6	11.7	51.7%	73%

The amount of ash and the percentage of coal recovered using mixed collectors were shown in Table 4.4. The correlation between the ash content and coal recovery rate was clearly depicted in Figure 4.3.

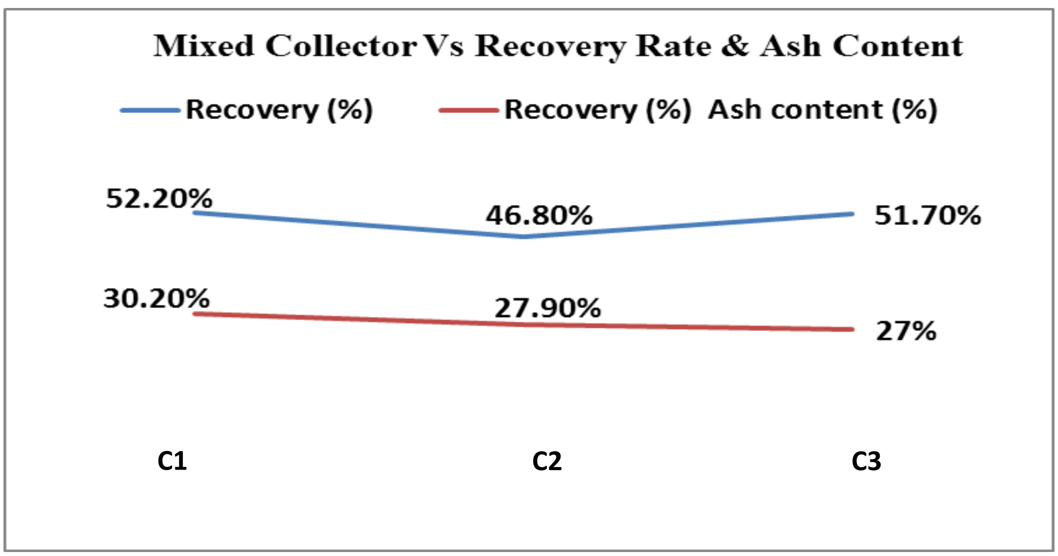

Figure 4. 3: Effects of Two Mixed Collector of Similar Dosage on Coal Recovery and Ash content

According to the data in Table 4.4 and Figure 4.3, the use of a mixed collector of kerosene and oleic acid results in the highest ash content (30.20%), but it also reaches a peak of 52.2% for the coal recovery rate. On the other hand, the kerosene and diesel oil mixture achieves a coal recovery rate of 51.70% with a lower ash level of 27%. Oleic acid and diesel oil, on the other hand, produce the lowest coal recovery, with an ash concentration of 27.90% and a coal recovery of 46.80%.

4.3.2 Effect Two Collectors with different dose Ratio as Mixed Collector

The impact of the sample collectors was evaluated as a mixed collector by varying their dosage proportions, assessing their influence on coal recovery rates and the ash content of the recovered coal. The findings of the experiment are presented in Table 4.5 below.

Table 4. 5: Coal Flotation Test Result for mixed collector with different dosage.

Sample code	Type of double mixed collector with different dosage	Collector dosage (ml)	Weight of raw coal sample <250µm screen	Weight of dry concentrate sample (g)	Weight of concentrate taken for combustion (g)	Weight of coal in the concentrate (g)	Weight of ash in the concentrate(g)
C4	Kerosene Oleic acid	2ml 3ml	100g	30.6	1.02	0.7746	0.2454
C5	Kerosene Oleic acid	3ml 2ml	100g	42.2	1.009	0.7285	0.2805
C6	Kerosene Diesel oil	2ml 3ml	100g	30.8	0.9886	0.7376	0.251
C7	Kerosene Diesel oil	3ml 2ml	100g	23	0.9987	0.8065	0.1922
C8	Oleic acid Diesel oil	3ml 2ml	100g	38.5	1.0199	0.7297	0.2902
C9	Oleic acid Diesel oil	2ml 3ml	100g	35.1	1.0599	0.7413	0.3186

In a similar fashion, the weights of coal in the concentrate (g) and the weight of ash in the concentrate (g) are presented in Table 4.5. The findings indicate that the concentrate weight is higher (0.8065g) when using a kerosene to diesel oil ratio of 3ml to 2ml, while the associated ash concentrate weight is 0.1922g, the lowest recorded. To provide a clearer understanding of the coal recovery percentage and the corresponding ash content percentage, equations 3.1 and 3.2 ,3.3 and 3.4 were applied, with the results displayed in Table 4.6 below.

Table 4. 6: Effects of Mixed Collector on recovery of coal and ash content

Sample code	**Type of double collector with the different dosage**	**Coal flotation concentrate**				**Recovery (%)**	**Grade (%)**
		Combustible matter /coal content (%)	**Ash content (%)**	**Amount of coal in the concentrate(g)**	**Amount of ash in the concentrate(g)**		
C4	Kerosene(2ml) Oleic acid(3ml)	76%	24%	23.3	7.3	38.1%	76%
C5	Kerosene(3ml) Oleic acid(2ml)	72.2%	27.8%	30.5	11.7	49.9%	72.2%
C6	Kerosene(2ml) Diesel oil(3ml)	74.6%	25.4%	23	7.8	37.6%	74.6%
C7	Kerosene(3ml) Diesel oil(2ml)	80.8%	19.2%	18.6	4.4	30.4%	80.8%
C8	Oleic acid(3ml) Diesel oil(2ml)	71.5%	28.5%	27.5	11	45%	71.5%
C9	Oleic acid(2ml) Diesel oil(3ml)	70%	30%	24.6	10.5	40.3%	70%

Table 4.6 illustrates the relationship between mixed collectors, varying in dosage ratios, and the percentages of coal recovery and ash content. The data shows that the highest coal recovery percentage was achieved with C5, where kerosene and oleic acid were mixed in a 3ml to 2ml ratio, and the corresponding resulting ash content percentage is 27.8%. In contrast, the lowest coal recovery occurred at C7, where the mixture of Kerosene and Diesel oil at a dosage ratio of 3ml to 2ml resulted in the minimum ash content of 19.2.

Similarly, a second coal recovery rate of 45% and an ash content of 28.5% were obtained by mixing Oleic acid with Diesel in a 3ml to 2ml ratio. The remaining coal recovery rates of 40.3%, 38.1%, 37.6%, and 30.4% were recorded using Oleic acid and Diesel at a 3ml to 2ml ratio, Kerosene and Oleic acid at a 2ml to 3ml ratio, Kerosene and Diesel at a 2ml to 3ml ratio, and Kerosene and Diesel Oil at a 3ml to 2ml ratio, respectively. The corresponding ash contents for these mixed collectors were 30%, 24%, 25.4%, and 19.2%. These results suggest that while certain collectors may be effective in coal recovery, they do not necessarily result in the lowest ash content.

Moreover, the correlation between mixed collector with ash content and coal recovery percentage is shown in figure 4.4.

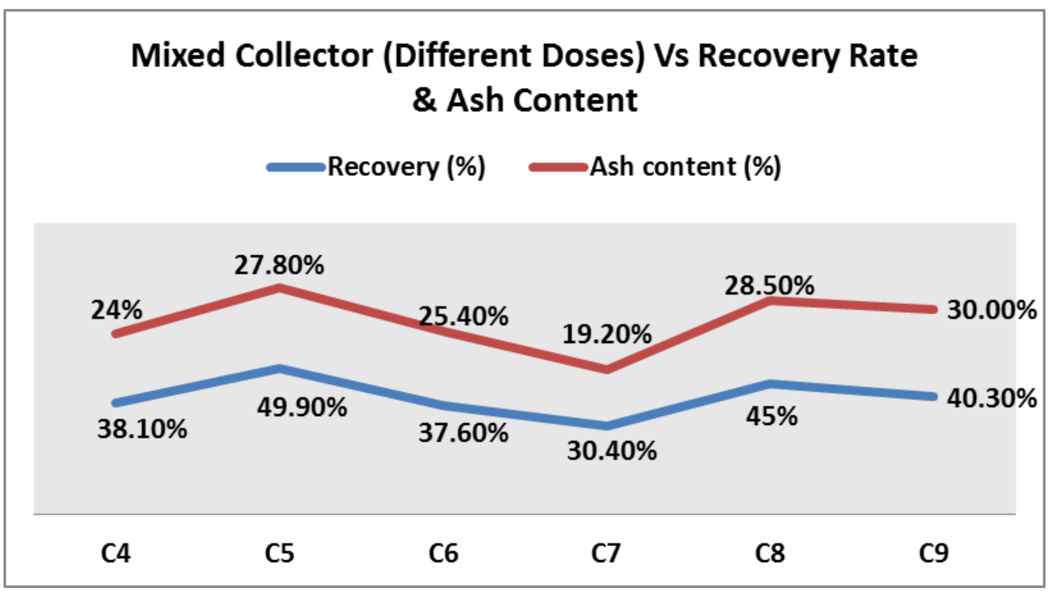

Figure 4. 4: Effects of Mixed Collector(Having Different doses) on the Coal recovery (%) and Ash Content

The data in Figure 4.4 compares the performance of mixed collector doses (C4 to C9) in terms of recovery rate (%) and ash content (%). The recovery rate varies significantly, with the highest recovery of 49.90% achieved at C5, while the lowest recovery of 30.40% occurs at C7. Conversely, the ash content peaks at 30% for C9 and drops to its lowest level of 19.20% at C7. These results highlight an inverse relationship between recovery rate and ash content, where higher recovery often corresponds to increased impurities.

Figure 4.4 also reveals that while certain mixed collectors, such as C5, excel in maximizing coal recovery, they simultaneously result in elevated ash content, which is undesirable for quality control. This trade-off suggests that optimizing collector doses requires balancing recovery efficiency with ash content reduction.

4.3.3 Effect Three Collectors with the same and different dose Ratio as Mixed Collector

Different literature's indicated that the efficiency of coal flotation is highly influenced by the type and dosage of collectors used in the process. This study also investigated the effect of three distinct collectors (Diesel Oil, Kerosene and Oleic Oil) combined in varying dose ratios as a mixed collector to study both the recovery rate (%) and ash content (%). By examining different formulations (C10 to C13), the research tried to identify optimal dose ratios that maximize coal recovery while minimizing ash content, a critical factor in determining product quality. The result is displayed in Table 4.7 show below.

Table 4. 7: Flotation Test Result for Triple mixed collector with the same and different dosage.

Sample code	Type of triple mixed collector with the different dosage	Collector dosage (ml)	Weight of raw coal sample <250µm screen	Weight of dry concentrate sample (g)	Weight of concentrate taken for combustion (g)	Weight of coal in the concentrate (g)	Weight of ash in the concentrate (g)
C10	Kerosene Oleic acid Diesel oil	2.5ml 2.5ml 2.5ml	100g	52.7	0.994	0.6486	0.3454
C11	Kerosene	2.5ml	100g	39.5	1.0237	0.6954	0.3283

	Oleic acid Diesel oil	3.5ml 2.5ml					
C12	Kerosene Oleic acid Diesel oil	3.5ml 2.5ml 2.5ml	100g	48.5	1.0439	0.6637	0.3802
C13	Kerosene Oleic acid Diesel oil	2.5ml 2.5ml 3.5ml	100g	50.8	1.0459	0.6938	0.3521

Table 4.7 presents experimental data for four mixed collector formulations (C10-C13) consisting of kerosene, oleic acid, and diesel oil in different dosage combinations. The flotation performance was assessed by examining concentrate weight, coal yield, and ash content. The results show that formulation C11 achieved the highest coal concentrate yield (0.6954g) with an associated ash content of 0.3283g. In contrast, C10 produced the lowest coal recovery (0.6486g) while generating slightly higher ash content (0.3454g) in the concentrate. This variation in performance demonstrates how different collector dosage ratios affect both recovery efficiency and product quality in the flotation process. To quantify the coal recovery efficiency and ash content of the mixed collector formulations, Equations 3.1, 3.2, 3.3 and 3.4 were employed to calculate the respective percentages, with the computational results systematically presented in Table 4.8.

Table 4. 8: Effects of Mixed Collector (the same and different proportion of doses) on coal recovery and Ash content

sample code	Type of triple mixed collector with the different dosage	Coal flotation concentrate				Recovery (%)	Grade (%)
		Combu stible matter /coal content (%)	Ash content (%)	Amount of coal in the concentrate(g)	Amount of ash in the concentrate(g)		
C10	Kerosene Oleic acid Diesel oil	65.3%	34.7%	34.4	18.3	56.3%	65.3%
C11	Kerosene Oleic acid Diesel oil	68%	32%	26.9	12.6	44%	68%
C12	Kerosene Oleic acid Diesel oil	63.6%	36.4%	30.8	17.7	50.4%	63.6%
C13	Kerosene Oleic acid Diesel oil	66.3%	33.7%	33.7	17.1	55.2%	66.3%

Table 4.8 shown above presents the flotation performance of four mixed collector formulations (C10–C13), each containing kerosene, oleic acid, and diesel oil in the same (C10) and varying dosages (C11-C13). Key metrics include recovery percentage (%), ash content (%), and absolute weights of coal and ash in the concentrate.

The experimental results demonstrate significant variations in flotation performance across the four mixed collector formulations. C10 achieved the highest coal recovery (56.3%) due to its balanced collector dosage, while C11 showed the lowest recovery (44%) but delivered lowest ash content (32%), highlighting the trade-off between recovery and puri

ty. Intermediate formulations C12 and C13 exhibited moderate performance, with C13 (55.2% recovery) presenting the most balanced results. The absolute weights further confirmed these trends, with C10 and C13 yielding higher coal amounts but more ash, whereas C11 produced the cleanest concentrate despite lower recovery.

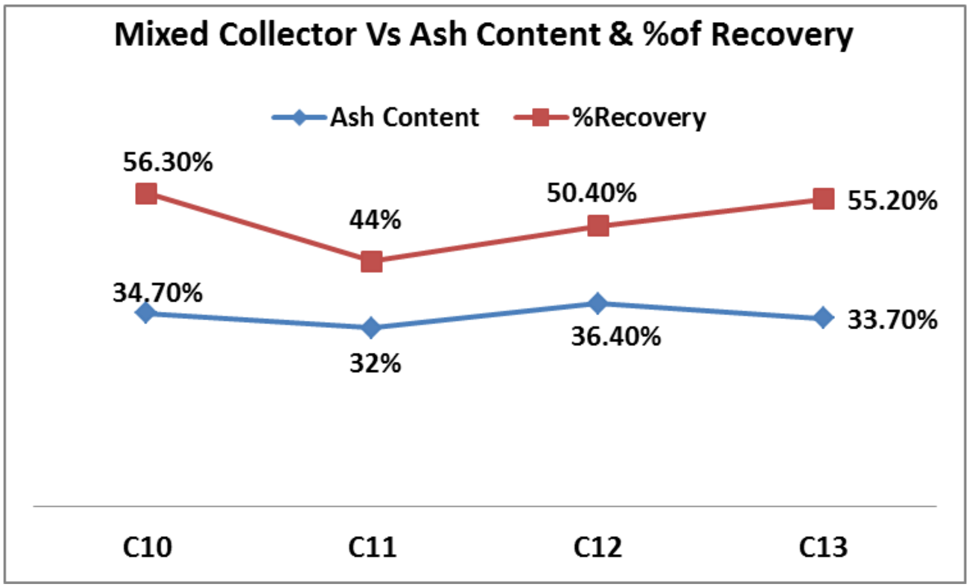

Figure 4. 5 Effects of Mixed Collectors (Three with the same and different doses) on the Coal recovery (%) and Ash Content

The impact of the three mixed collectors on ash content and recovery percentage is illustrated in Figure 4.5. The results show that sample C11 had the lowest ash content (32%), but its corresponding recovery percentage was also relatively low (44%). In contrast, the highest recovery percentage (56.3%) was observed in sample C10, which exhibited a moderate ash content of 34.7%. The optimal balance between ash content and recovery was achieved in sample C13, with a recovery percentage of 55.2% and an ash content of 33.7%. Generally, a higher recovery percentage tends to coincide with an increase in ash content.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusions

A thorough investigation into how individual and combined collectors affect coal flotation performance has yielded important information about the connection between ash content and recovery efficiency. The findings showed that flotation results are mostly dependent on the type of collector and the ratios used. Diesel oil, oleic acid, and kerosene were examples of individual collectors that had distinct performance characteristics; oleic acid prioritized purity at the expense of some output, while kerosene and diesel produced better recovery rates but a moderate ash level. These findings emphasize how important it is to select collectors based on certain process objectives, whether those objectives are to improve recovery or lower contaminants.

Research on mixed collector systems has shown that varying the proportions of collectors can enhance flotation efficiency. For example, equal amounts of kerosene, oleic acid, and diesel oil (C10) achieved the highest recovery rate of 56.3%, while formulations with a greater concentration of oleic acid (C11) resulted in the lowest ash content at 32%, albeit with a decrease in recovery. Interestingly, the triple mixed collector C13 proved to be a well-balanced choice, delivering a competitive recovery rate of 55.2% alongside acceptable ash levels of 33.7%. These findings underscore the effectiveness of customized collector combinations in balancing yield and product quality.

The inverse correlation between recovery rates and ash content was a consistent observation throughout all experiments. Increased recovery rates were frequently associated with higher ash content, highlighting the difficulty of optimizing both factors simultaneously. This trade-off requires a thorough assessment of industrial priorities, as processes focused on yield may accommodate higher ash levels, while those that prioritize purity must accept reduced recovery rates. Additionally, the findings indicate that mixtures dominated by kerosene especially diesel oil tend to improve recovery but reduce selectivity, whereas oleic acid enhances purity at the expense of yield.

5.2. RECOMMENDATIONS

5.2.1 Challenges in Low-Grade Coal Processing

The process of upgrading low-rank coal through flotation is more challenging compared to that of bituminous and/or anthracite coal, particularly for micro-fine coal slimes. This difficulty arises from the developed porosity, the abundance of oxygen surface functional groups, and the low likelihood of collision between bubbles and particles. Low-grade coals are typically characterized by low specific energy due to high moisture and/or ash content, or they may result in significant emissions of concern. These coals are often classified as lignite's or sub-bituminous coals. There is an increasing demand for the utilization of these low-grade coals in response to the growing need for power generation.

Low-rank coal is difficult to float using oily collectors due to the rich oxygen-containing functional groups on the surface. In recent years, a variety of mixed collectors have been used to enhance the low-rank coal flotation

The study's findings highlight several key recommendations for optimizing coal flotation performance. I would like to recommend first, collector blends should be carefully tailored by adjusting the ratios of kerosene, oleic acid, and diesel oil to achieve the desired balance between recovery efficiency and ash content. Additionally, further testing of intermediate dosages between the studied ratios could help identify more precise optima, and diesel oil-dominant blends should be used judiciously due to their tendency to increase ash content despite higher recovery rates.

Future studies should investigate creative methods to address the inherent trade-off between recovery and ash content. I would like to Additionally recommend, economic feasibility assessments are necessary to determine the cost-effectiveness of optimized blends for large-scale industrial use. When implemented thoughtfully, these strategies can greatly enhance flotation efficiency while aligning with particular operational goals, whether the aim is to maximize recovery, reduce impurities, or achieve a balanced performance. The findings serve as a foundation for further research and industrial applications in coal flotation.

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