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Research Article

Effects of Single and Mixed Collectors on Low-Grade Coal Flotation: In the Case of Gamo Zone Coal, Southern Ethiopia

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Abstract

This study investigated the effectiveness of single and mixed collectors in enhancing the flotation efficiency of low-grade coal from the Gamo region of Ethiopia, focusing on recovery rates and ash content. 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, Diesel-rich 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, Ash Content, Grade, Recovery

1. Introduction

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 de-

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velopment of diverse coal fields [2].

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 [22]. 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 R. K. 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 [8].

It is known that coal is the primary fossil fuel and supplies approximately 42% of the electricity to the world. It will still hold a dominant position in the energy supply until 2050 ([6]. Coal is the main fossil fuel in many countries, accounting for almost 70% of the primary energy consumption especially in China [4, 27]. 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 [16].

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 [15, 21].

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 [3]. 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 [4, 18]. 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 [7, 17].

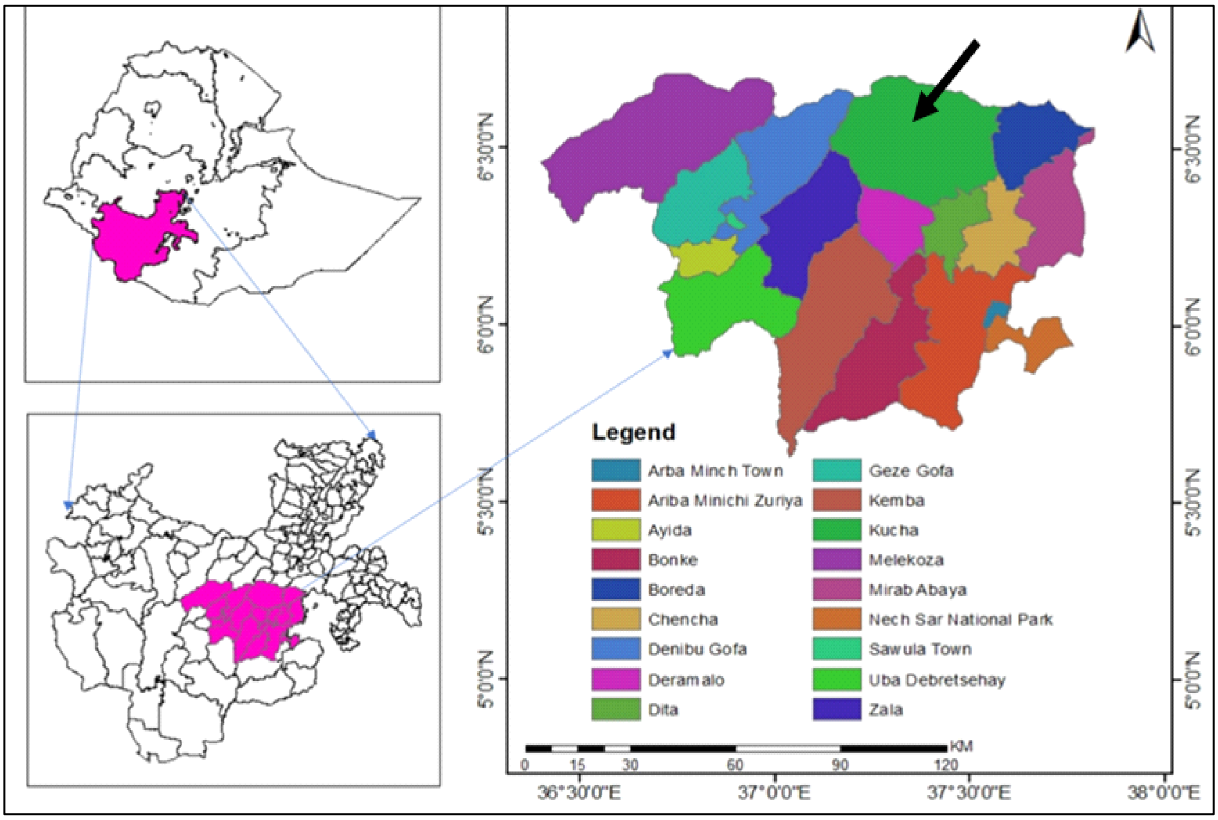

Figure 1. Location of the Study Area (Dejen, Soni, and Semaw. 2019).

Separating combustible matter from mineral-formed ash has an important role in improving the calorific value and utilization efficiency of fine coal. 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 [23, 27].

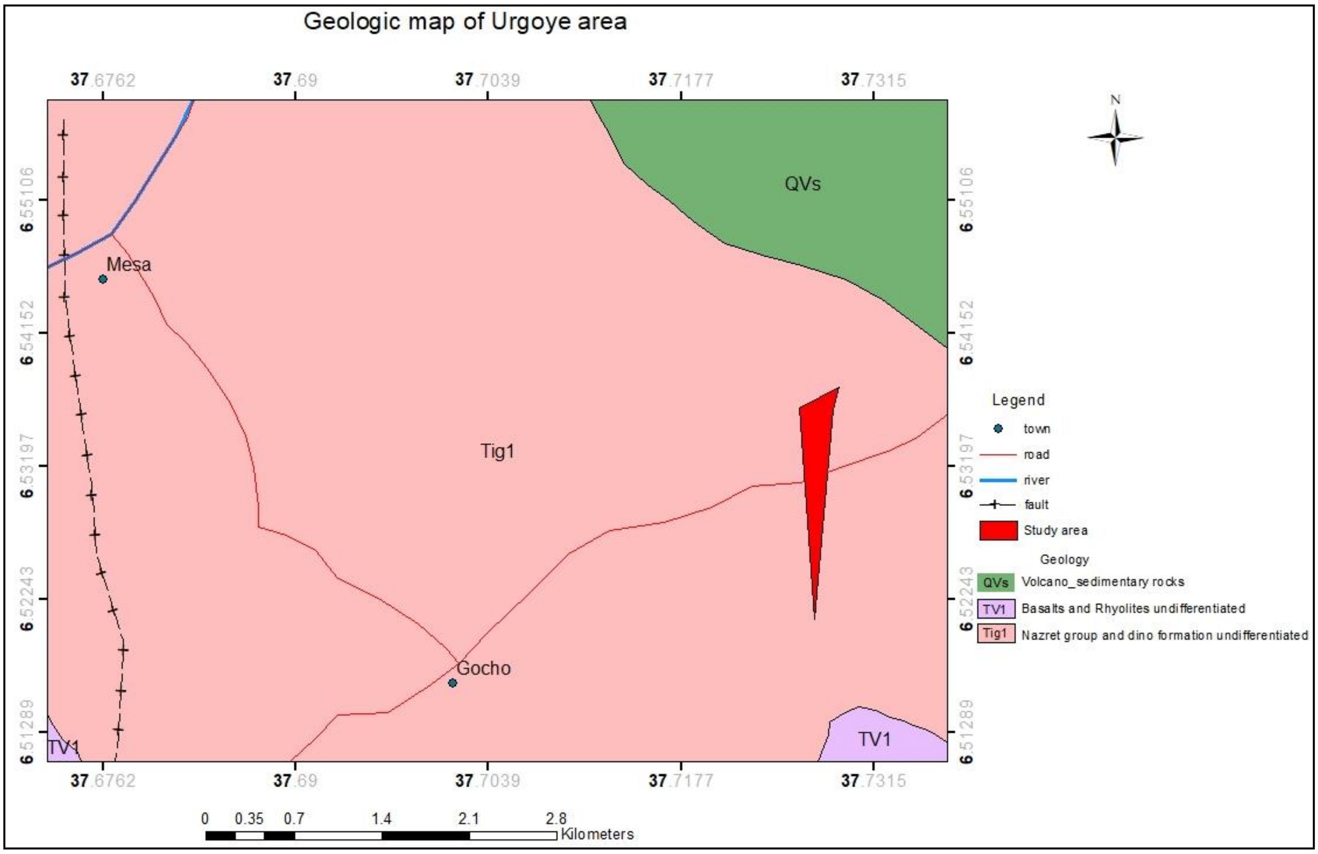

Figure 2. Geological map of the study area (Aman Yismaw, Bezayit Mitiku 2015).

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 [19, 26]. 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, Southern Ethiopia.

1.1. Location of the Study Area

The Urgoye coal mining region is situated in the Gamo Gofa Zone of southern Ethiopia. Coal extraction occurs in the Kucha Wereda, which is part of the broader Gamo 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 [9]. (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.

1.2. Geology of the Study Area

The northern portion of the 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 [24, 32].

1.2.1. Lower Basalt, Aphyric to Porphyritic Rhyolites and Trachytes (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 [1].

1.2.2. Nazareth 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 [1].

1.2.3. Materials and Methodology

Approximately 5 kilograms of Gamo coal bulk 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 250 µm. 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.

1.2.4. Lab Equipment

The basic lab Equipment's that used to conduct the study was lumps of coal which was obtained from Gamo region of Southern Ethiopia and the equipment's that were used for this work includes; laboratory jaw crusher (RoHs53743) Figure 3(A), Centrifugal milling machine (Figure 3(B)), sieves with different mesh sizes (Figure 3(C)), laboratory wedge flotation cell (Groppel 98) Figure 3(D), Oven (Figure 3(E)), and Furnace (Figure 3(F))

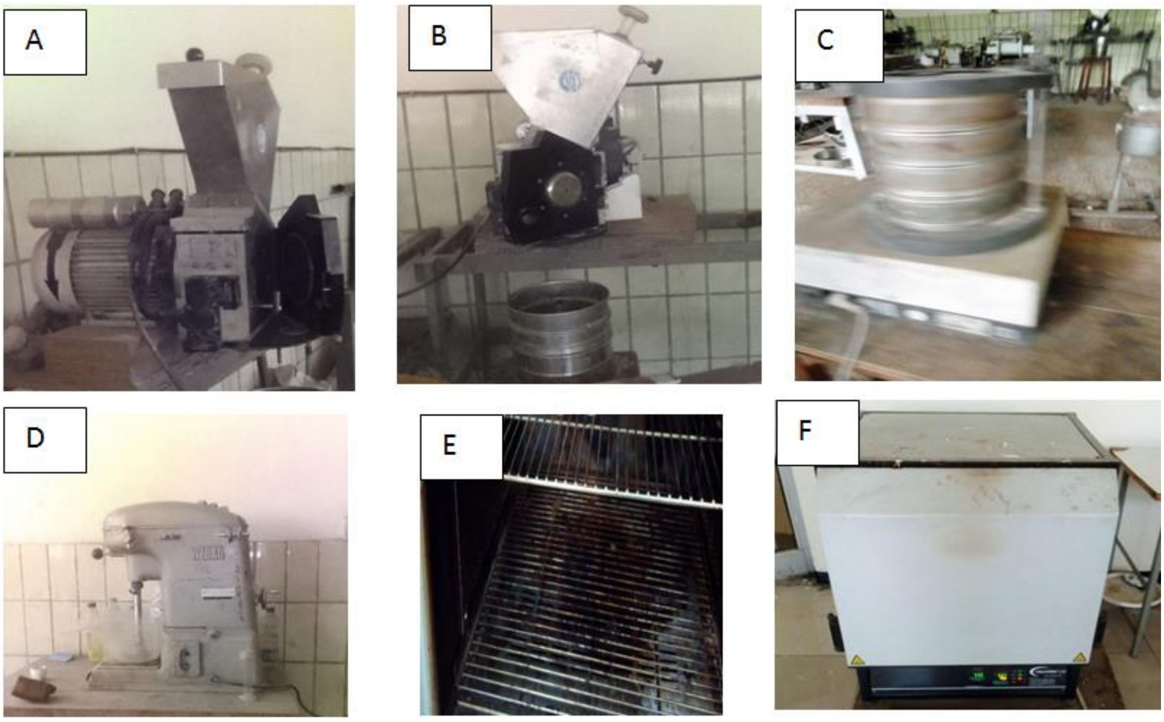

Figure 3. *Laboratory equipment used in this project.*

1.2.5. 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 [5, 9-13].

1.2.6. 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 [28-31, 33].

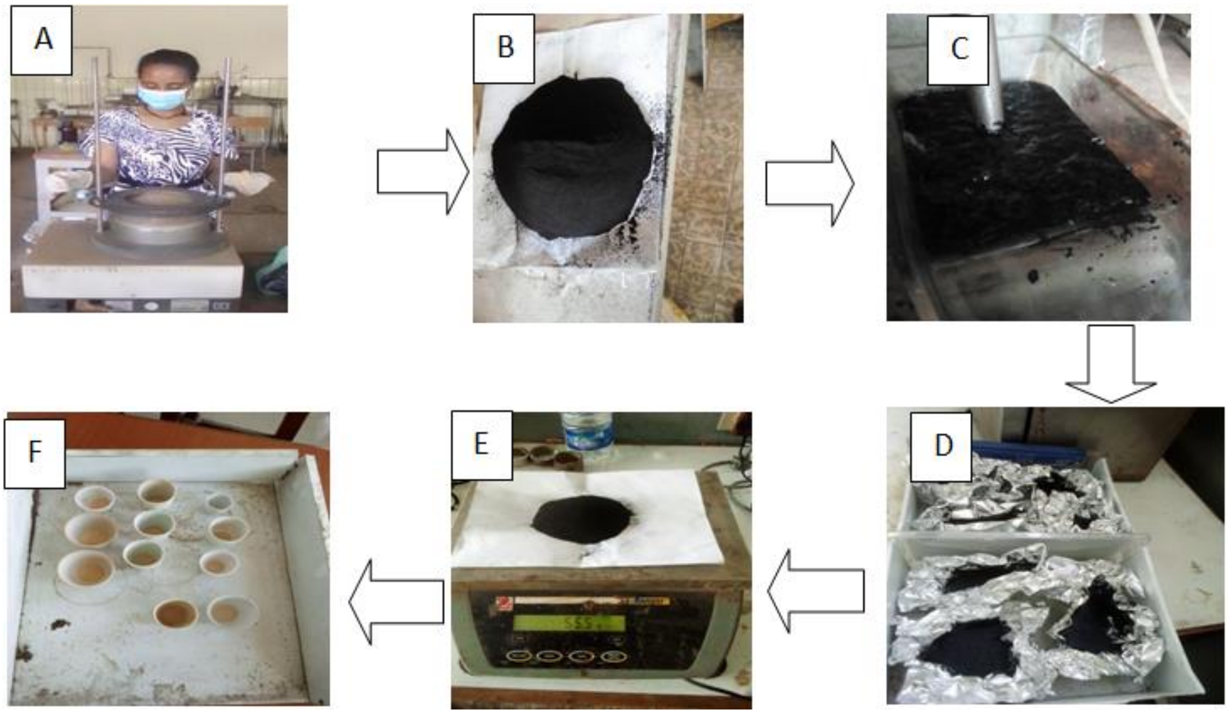

Figure 4. *Steps used in the flotation processes.*

2. Result and Discussion

The experiments aimed to determine how individual and combined collectors affected two crucial 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 [25, 26]. 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 [8, 20, 23].

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. The yield percentage Ash content, influenced by single Collector having the same dosage, was analyzed, with the findings presented in Table 1.

Table 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 <250 µm 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 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 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.

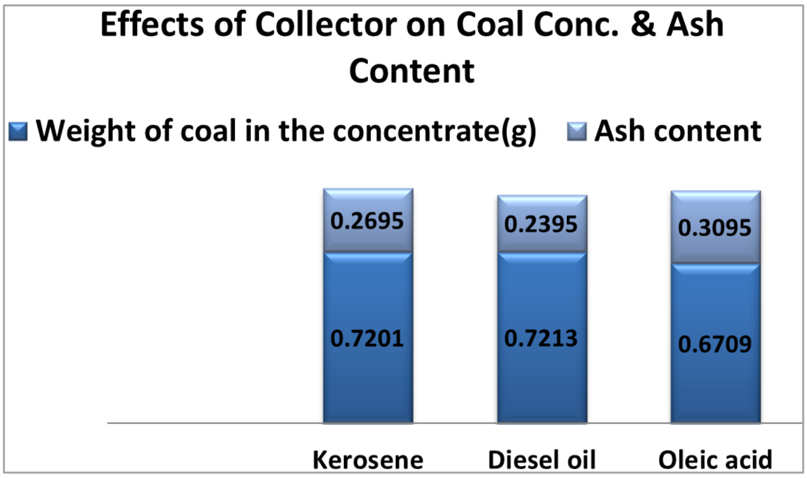

Figure 5. Effects of Single Collector on Coal Con. And Ash Content.

Using a similar methodology, Figure 5 shows that the ash content increases while the coal concentrate decreases (0.3095, 0.6709g) when oleic acid is used, whereas the lowest ash content and the highest coal concentrate were observed (0.2395, 0.7213g) with diesel oil.

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 different equation and the results were presented in the Table 2 below.

Table 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%

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)		
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%).

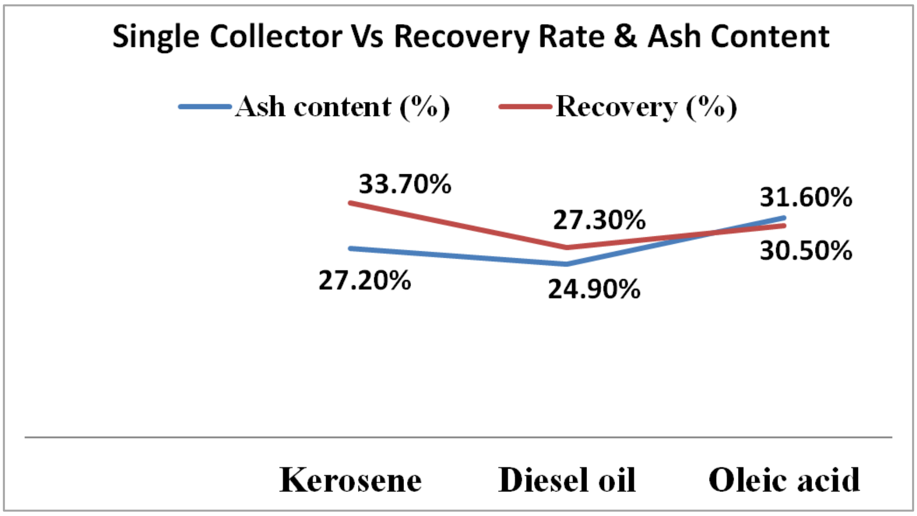

Figure 6. The effects of single collector on the recovery rate & ash content.

In a manner similar to Table 2, Figure 6 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.

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.

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 3 below.

Table 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 <250 µm 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

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
C2	Oleic acid Diesel oil	2ml 2ml	100g g010	39.6	1.0036	0.7239	0.2797
C3	Kerosene Diesel oil	2ml 2ml	100g 0	43.3	1.052	0.7678	0.2842

In Table 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 shown in Table 4 below

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

Sample code	Type of double collector with the d/t dosage	Coal flotation concentrate					
		Combustible matter /coal content (%)	Ash content (%)	Amount of coal in the concentrate (g)	Amount of ash in the concentrate (g)	Recovery (%)	Grade (%)
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. The correlation between the ash content and coal recovery rate was clearly depicted in Figure 7.

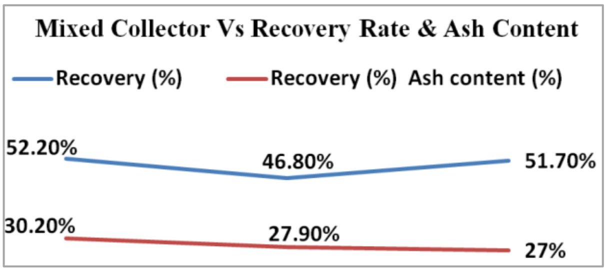

Figure 7. Effects of Two Mixed Collector of Similar Dosage on Coal Recovery and Ash content.

According to the data in Table 4 and Figure 7, 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%.

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 5 below.

Table 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 <250 µm 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	100	30.6	1.02	0.7746	0.2454
C5	Kerosene Oleic acid	3ml 2ml	100	42.2	1.009	0.7285	0.2805
C6	Kerosene Diesel oil	2ml 3ml	100	30.8	0.9886	0.7376	0.251
C7	Kerosene Diesel oil	3ml 2ml	100	23	0.9987	0.8065	0.1922
C8	Oleic acid Diesel oil	3ml 2ml	100	38.5	1.0199	0.7297	0.2902
C9	Oleic acid Diesel oil	2ml 3ml	100	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 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, the results displayed in Table 6 below.

Table 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 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 8.

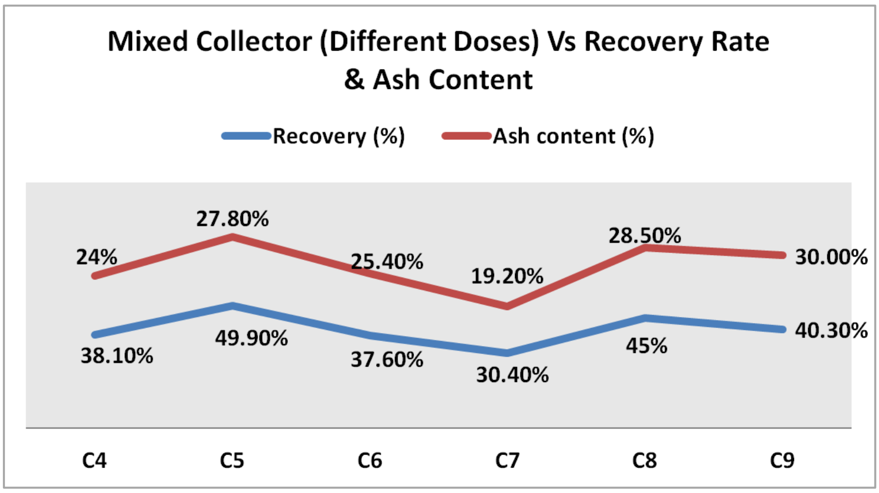

Figure 8. *Effects of Mixed Collector (Having Different doses) on the Coal recovery (%) and Ash Content.*

The data in Figure 8 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 8 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.

Effect Three Collectors with Different dose Ratio as Mixed Collector

Different literatures 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 7 show below.

Table 7. *Flotation Test Result for double mixed collector with different dosage.*

Sample code	Type of triple mixed collector with the different dosage	Collector dosage (ml)	Weight of raw coal sample <250 μm 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 Oleic acid Diesel oil	2.5ml 3.5ml 2.5ml	100g	39.5	1.0237	0.6954	0.3283
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 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, the computational results systematically presented in Table 8.

Table 8. *Effects of Mixed Collector (different proportion of doses) on coal recovery and Ash content.*

sample code	Type of triple mixed collector with the different dosage	Coal flotation concentrate					
		Combustible matter /coal content (%)	Ash content (%)	Amount of coal in the concentrate (g)	Amount of ash in the concentrate (g)	Recovery (%)	Grade (%)
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	63.6%	36.4%	30.8	17.7	50.4%	63.6%

sample code	Type of triple mixed collector with the different dosage	Coal flotation concentrate					
		Combustible matter /coal content (%)	Ash content (%)	Amount of coal in the concentrate (g)	Amount of ash in the concentrate (g)	Recovery (%)	Grade (%)
	Diesel oil						
C13	Kerosene Oleic acid Diesel oil	66.3%	33.7%	33.7	17.1	55.2%	66.3%

Table 8 shown above presents the flotation performance of four mixed collector formulations (C10-C13), each containing kerosene, oleic acid, and diesel oil in varying dosages. 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 purity. 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 [10-12, 14].

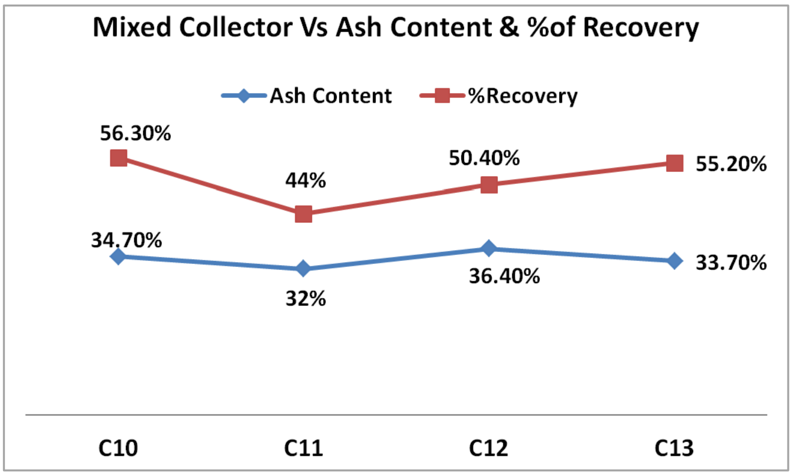

Figure 9*. Effects of Mixed Collectors (Three with different doses) on the Coal recovery (%) and Ash Content.*

The impact of the three mixed collectors on ash content and recovery percentage is illustrated in Figure 9 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.

3. Conclusion

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 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 tend to improve recovery but reduce selectivity, whereas oleic acid enhances purity at the expense of yield.

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Abbreviations

ASTM	American Society for Testing Materials
g	Gram
LRC	Low Rank Coal
ml	milliliter
AAiT	Addis Ababa Institute of Technology
μm	Micro Meter
℃	Celsius scale

Author Contributions

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Availability of Data

The data used in the study will be available upon request.

Conflicts of Interest

The authors declare no conflict of interests.

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