



**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**CENTER FOR ETHIO–MINES DEVELOPMENT (CEMD)**

Master of Engineering project entitled: “The flotation response of Dedo coal deposit, Jimma Ethiopia: Implication to improve the quality of coal”

A project submitted to: Center for Ethio-Mines Development (CEMD) in partial fulfillment of Master of Engineering in Mineral Engineering.

**By: Dejene Amane**

**Advisor: Dr. Melesse Alemayehu**

June, 2023

Addis Ababa University

Addis Ababa, Ethiopia

**Abstract**

The purpose of this study was to investigate the flotation response of the Dedo coal deposit and to improve its quality. In this project, chemical reagents were used to induce hydrophobicity in hydrophilic coal particles present in coal slurry, and particularly froth flotation techniques were employed. To obtain a general understanding of the floating response of coal from the study area, the yield of floated coal was estimated. The quality of coal before beneficiation (froth flotation) in this project was characterized by a moisture content of 13.63%, volatile matter of 33.45%, ash of 25.66%, sulfur of 0.36%, and calorific value of 4806 cal/gm. After beneficiation, the moisture content was 11.06%, volatile matter was 25.63%, ash was 20.28%, sulfur was 0.25%, and calorific value was 5029.38 cal/gm. These results indicate that impurity contents such as ash, mineral matter, and sulfur resources were reduced, and the calorific value of coal was increased by applying successful froth flotation

**Keywords:** froth flotation, Dedo coal deposit, flotation response, particle size, impeller speed

# Contents

Abstract .....	i
Contents .....	ii
List of Figures .....	iii
List of Tables .....	iv
1. INTRODUCTION .....	1
1.1. Background .....	1
1.3. Geology of the area.....	3
1.4. Statement of the problem .....	4
1.5. Objectives .....	4
1.5.1. General objective .....	4
1.5.2. Specific objectives .....	4
1.6. Significance.....	4
2. LITERATURE REVIEW .....	4
2.1. Basic Principles of froth flotation .....	5
2.2. Froth flotation of coal .....	5
3. MATERIALS AND METHODS .....	6
3.1. Materials .....	6
3.2. Methodology.....	7
3.2.1. Desk study.....	7
3.2.2. Sample collection and laboratory work.....	7
3.2.3. Data processing and interpretation.....	8
4. RESULTS AND DISCUSSIONS .....	10
4.1. Optimized parameters .....	10
4.2. The flotation results .....	10
4.3. Coal quality improvement.....	11
4.3.1. The determination of moisture content amount .....	12
5. CONCLUSIONS AND RECOMMENDATIONS .....	14
5.1. Conclusions.....	14
REFERENCES .....	15

## List of Figures

Figure 1 : Map of the area (a, Ethiopian regions, b, Oromia zones, c, Dedo woreda) .....	2
Figure 2 : Geological map of the area.....	3
Figure 6: Laboratory equipments used .....	6
Figure 7: The effects of impeller speed and particle size on the flotation of coal. ....	9
Figure 8: Froth floatation procedures and resulting coal particles.....	11
Figure 9 : The proximate analysis of raw and treated coal sample. ....	12

## List of Tables

Table: 1. The coal flotation experimental results.....	8
Table: 2. Details of the laboratory survey.....	8
Table: 3. Optimum values for floatation of the coal .....	10
Table: 4. The proximate, sulfur, fixed carbon and calorific value results for both raw and treated coal.....	11

# **1. INTRODUCTION**

## **1.1. Background**

Coal is an organic sedimentary rock composed of carbon, hydrogen, and oxygen that is capable of combustion. Coal formed from vegetation that has been compressed between layers of rock over millions of years and changed by pressure and temperature. It is estimated that there are over 909 billion tons of known coal reserves worldwide, enough to last for over 150 years. The countries with the largest coal reserves are the United States, Russia, China, India, South Africa, Ukraine, Serbia, Mongolia, and Brazil. South Africa has the most significant coal deposit in Africa, while Ethiopia is estimated to have about 300 million tons of coal. Coal is primarily used for power, steel, cement, activated carbon, and liquid fuel production. The flotation properties of coal depend on various factors such as its mineralogical and petrographic composition, rank, degree of oxidation, and inorganic impurities. Low rank coals, such as lignite, are challenging to float cleanly due to their high oxygen content, high porosity, and abundance of polar functional groups on their surface. Flotation technology can be used to refine coal and phosphorus. The aim of this project was to develop process parameters for froth flotation of coal in Dedo, Jimma, Ethiopia, to increase the concentration of low coal deposits for more economical processing. The effects of particle size and impeller speed on coal flotation in the Dedo coal deposit have been well understood.

## **1.2. Location and accessibility of the investigated area**

The selected study area Dedo coal deposit is located in the Jimma Zone, south west Ethiopia (Figure 1). Dedo coal deposit is considered as one of the most significant coal reserve in Ethiopia. The deposit is situated approximately 415 kilometers southwest of Addis Ababa and covers an area of about 194 square kilometers. The coal deposit in Dedo is estimated to contain up to 430 million tonnes of coal reserves (Teshome et al., 2020). Coal mining activities at the Dedo coal deposit have been planned and executed by East Africa Metals, a mineral exploration company based in Vancouver, Canada, and the Ethiopian Ministry of Mines, Petroleum, and Natural Gas. The initial exploration work began in 2018, and in 2019 the companies announced significant results regarding the coal quality and quantity at the Dedo coal deposit. The Dedo coal deposit's development is essential for Ethiopia's economic growth, particularly in the energy and mining sectors.

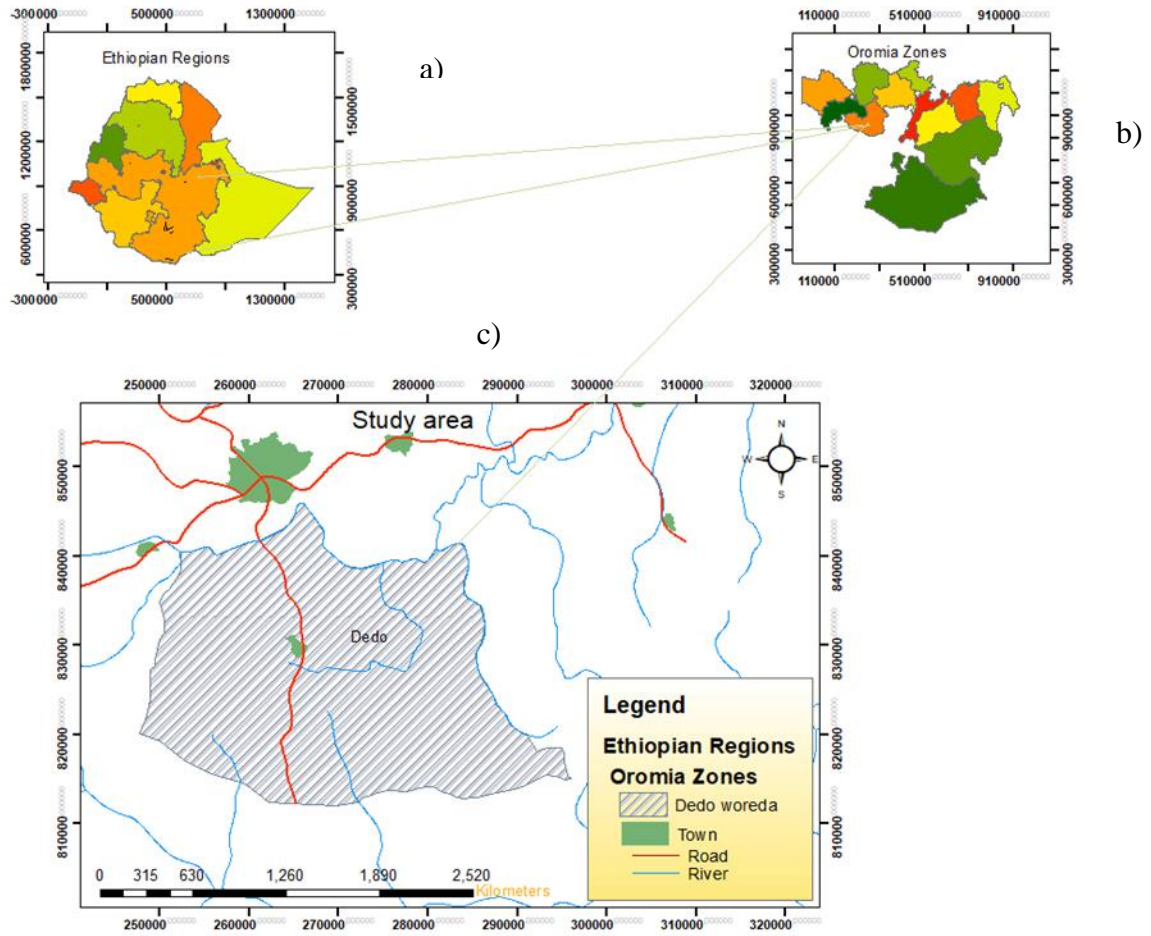


Figure 1 : Map (a, Ethiopian regions, b, Oromia zones, c, Dedo woreda)

### 1.3. Geology of the area

The Dedo coal basin in general is underline by two major rock types; volcanics and sedimentary rocks. There are known localized minor occurrences of intrusive materials like pyroclastic rocks. The compositional variations in the volcanic rocks range widely from basic to acidic. The geology of the area where Dedo coal deposit is located as part of the Neoproterozoic to Cretaceous-age sequences, which consist of sedimentary rocks such as sandstones, shales, siltstones, and limestones (Alemayehu et al., 2015). The coal-bearing formation in Dedo is part of the Adola Belt, which is located in the southern part of Ethiopia and is known for its gold and base metal deposits (Alemayehu et al., 2015; Hunde, 2016). The Adola Belt is a northwest-trending, elongated, and narrow tectonic zone that extends for about 400 km in the southern part of Ethiopia (Hunde, 2016). The Adola Belt is composed of several sub-belts, including the Moyale, Mega, and Kenticha sub-belts (Hunde, 2016). The sedimentary rocks in the area where Dedo coal deposit is located are part of the Kenticha sub-belt.

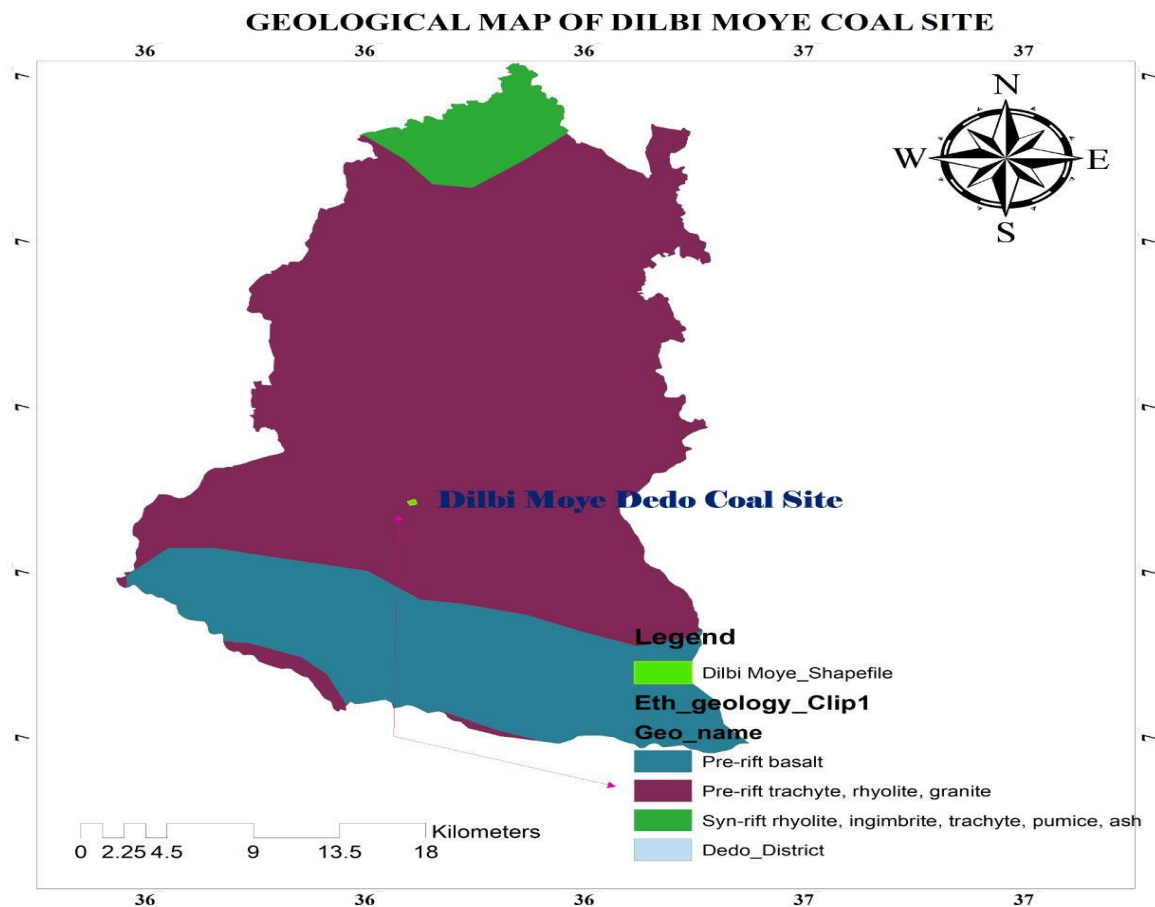


Figure 2 : Geological map of the area

#### **1.4. Statement of the problem**

Due to the absence of high grade coal in Ethiopia, it is advisable to increase demand to process low grade coal to improve its grade by using froth flotation method. There is no tangible research conducted on the flotation characteristics of Dedo coal deposit. Therefore, the main benefits of these project is to identify the flotation response of Dedo coal deposit and to overcome the problems that may face on the processing of coal by flotation.

#### **1.5. Objectives**

##### **1.5.1. General objective**

The general objective of the study is to identify the flotation characteristics of Dedo coal deposit and to separate fine particles of coal contained in coal slurry.

##### **1.5.2. Specific objectives**

- To improve the flotation of particles of coal those have a more hydrophilic nature.
- To enhance fine coal particle quality by lowering contaminant

#### **1.6. Significance**

This study is focused on creating process parameters for froth flotation in case of the Dedo coal deposit, Jimma Ethiopia, and its important uses. By using these methods, low coal concentrations were raised to levels that could be handled more profitably. It is well known how the size of particle and the impeller speed affect coal flotation in the case of the Dedo coal deposit.

Generally this project is done to benefit RIALMINE TRADING PLC and another companies those who have an interest to process the coal from Dedo, Jimma Ethiopia being used as an input to mitigate the difficulties during flotation of coal.

## **2. LITERATURE REVIEW**

### **2.1. Basic Principles of froth flotation**

According to variety in the ability of air bubbles to attach themselves specifically to different mineral surfaces in mineral/water slurry, the froth flotation process is used to physically separate particles (Eliseu, Geraldo Conde et al., 2019). The separation of sulfide minerals from silica gangue (and from other sulfide minerals), potassium chloride (sylvite) from sodium chloride (halite), coal from ash-forming minerals, silicate minerals from iron ores, phosphate minerals from silicates, and even non-mineral tasks like de-ink recycling newsprint are just a few of the many tasks it is used for currently. It is particularly useful for processing fine-grained ores that are not amenable to conventional gravity concentration.

### **2.2. Froth flotation of coal**

To overcome the difficulties associated with coal processing, various researchers have attempted to create beneficiation technology to minimize the impurity of coal so that it conforms to its application standards (Mishra et al., 2015; Liu et al., 2018; Behera et al., 2018). According to Matis, K. A., G. P. Gallios, and K. A. Kydros (1993), froth flotation is the most adjustable technique for the physical separation of particles based on differences in how well air bubbles attach to various mineral surfaces in mineral or coal slurries. While particles that are entirely wet remain in the liquid phase, those linked to air bubbles are transported to the surface and eventually eliminated. Currently, it is being used as a versatile method to separate sulphide minerals from silica gangue (and from the other sulphide minerals), potassium chloride from sodium chloride, coal from ash-forming minerals, silicate minerals from iron ores, phosphate minerals from silicates, and even non-mineral applications like de-ink recycled newsprint. It is especially helpful for coals or fine-grained ores that can't be concentrated using gravity. The most effective method for reducing polluting substance and improving the fine particles is coal flotation (Majumder and Barnwal et al., 2011). The froth flotation theory is complicated and still not fully understood. Numerous issues seen in coal preparation plants have led to this reality (Ye et al., 2017). Knowing the effects of different parameters on the fine particle size separation and controlling flotation performance for system execution are crucial for overcoming these challenges.



### 3. MATERIALS AND METHODS

#### 3.1. Materials

The basic material that used to conduct the study was lumps of coal which was obtained from Dedo coal deposit, Jimma Ethiopia and the equipments that were used for this work includes; laboratory jaw crusher (RoHs53743) Figure 6A, laboratory centrifugal mill (Figure 6B), sieves with different mesh sizes (Figure 6C) and laboratory wedag flotation cell (Groppel 98) Figure 6D. The chemical reagents that were used in this work include Kerosene and N-octanol.



Figure 3: Laboratory equipments use

## **3.2. Methodology**

Various tasks were accomplished before starting this work. The office work includes review literatures, scientific journals and relevant books were seen critically for the successful accomplishment of this work. The bulk coal sample was collected from the study area and sample preparation was done in the laboratory. The collected sample was analyzed in a laboratory and different experiments were conducted to have an overall understanding of the flotation behavior of Dedo coal deposit and to improve its quality.

### **3.2.1. Desk study**

Literature review, scientific journals, relevant books (from websites, libraries) and secondary data that obtained from the companies and Ethiopian Geological Institute was critically reviewed in this project.

### **3.2.2. Sample collection and laboratory work**

About 5kg of Dedo coal bulk sample that was collected from the open pit mine opened by the RIALMINE TRADING PLC was used in this work. The sample coal was crushed and pulverized (reduced to fine particles). The coal sample was crushed and ground, and then separated using sieves and an automated sieve shaker. The sieves were arranged in order of decreasing mesh size, with the largest mesh size at the top. For each experiment, approximately 100g of the sample was mixed with 2L of tap water and stirred for three minutes using high and low impeller speeds, until the coal particles were completely wetted by closing the air valve with scotch. Next, 5ml of kerosene was added as a collector and agitated for another three minutes. Additionally, 40ppm or 0.12ml of N-octanol was added as a frother, and an air valve was opened to supply air to the flotation cell to form bubble particles. When the bubble formation began, 1L of water was added to fill the capacity of the cell. The formations of bubble particle continued until it overflowed the cell and were collected. Collection and foam formation were continued until white foam was observed, indicating that all solid particles in the cell were attached to the kerosene oil collectors.

Generally, the collected particle was dried in a hot oven at 80°C for three hours and the floated concentration yield was calculated as the equation below for each of experiments. Therefore, the performance calculation was done for each and every experiment in this study depending on the formula below.

$$\text{Yield} = \frac{\text{Mas of the concentration}}{\text{Mass of the feed}} \times 100 \% \dots\dots\dots (1)$$

Table: 1. The coal flotation experimental results

Sample code	Particle size(μm)	Impeller Speed(rpm)	Feed(g)	Mass of coal concentrated(g)	Yield %
D11	-500+250	1500	100	47	47
D21	-125+63	1500	100	53	53
D31	-500+250	2500	100	50	50
D41	-125+63	2500	100	67	67
D12	-500+250	1500	100	49	49
D22	-125+63	1500	100	54	54
D32	-500+250	2500	100	52	52
D42	-125+63	2500	100	66	66

Table: 2. Details of the laboratory survey

Mines	Crusher type	Mill type	Number of mill	Number of variables	Coal flotation reagents	Mine location
Coal	Jaw crusher	Centrifugal mill	1	2	1, Kerosene 2, N-octanol	Dedo coal deposit, Jima Ethiopia

### 3.2.3. Data processing and interpretation

By removing any associated pollutants, the froth flotation method was employed to enhance the coal from the Dedo coal deposit. The coal from the research area floating characteristics were investigated after a number of trials. To determine the impacts of coal's particle size and impeller speed in this situation, studies on coal flotation were carried out. The coal particle size and flotation impeller speed were the experimental variables in this case since they are the variables that influence the coal flotation procedures. The model parameters were subjected to an ANOVA analysis using the statistical program MINITAB to determine the important factors affecting flotation performance.

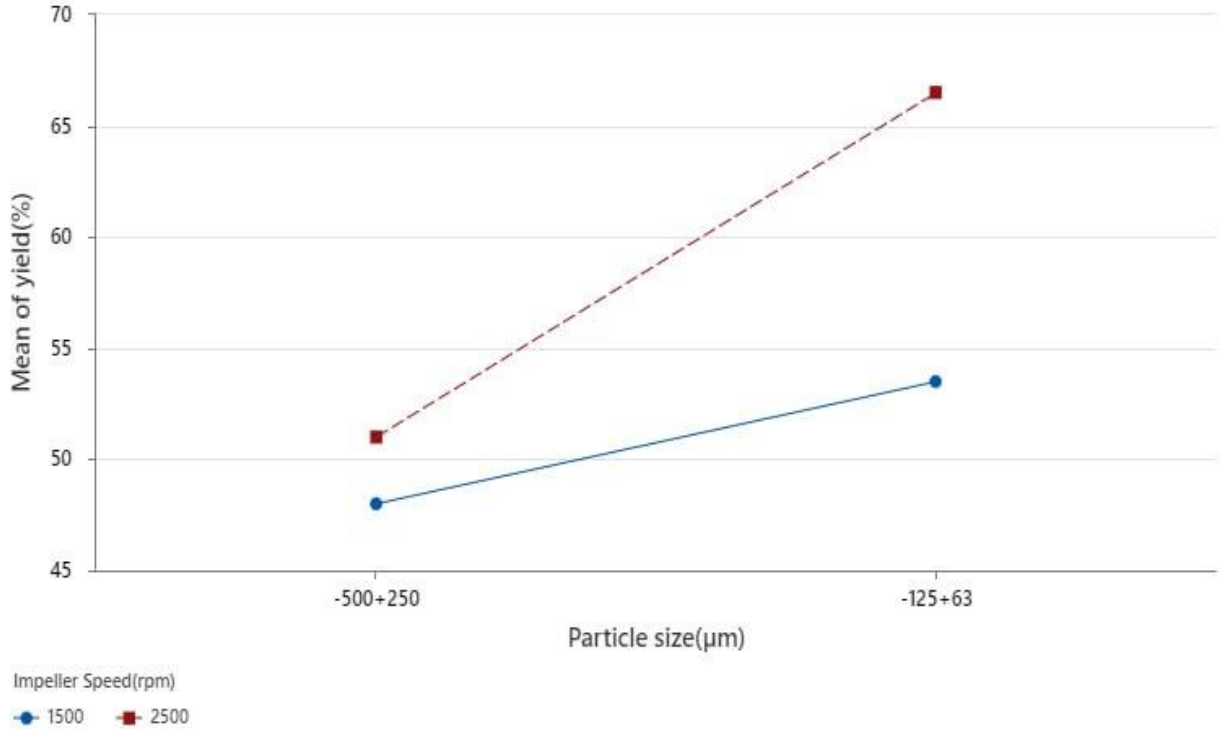


Figure 4: The effects of speed of the impeller speed and the size of particle

As indicated from Figure 7 the maximum concentrate yield obtained by flotation was 67% when a coal particle size of  $-125+63\mu\text{m}$  was floated with impeller speed of 2500 rpm and the minimum concentrate yield obtained by flotation was 47% by floating with impeller speed of 1500 rpm when a coal particle size of  $-500+250\mu\text{m}$  was floated keeping the mass of coal, conditioning time, reagent dosages constant for each experiments. This shows that the particle size and flotation impeller speed have an impacts on flotation of coal. If we decrease particle size

According to Figure 7, it appears that larger particles (250-500  $\mu\text{m}$ ) are more difficult to float, as they tend to enter the flotation cell and fail to float. The experiments showed that increasing the impeller speed and reducing particle size resulted in a maximum yield, while decreasing impeller speed and increasing particle size resulted in a minimum yield. However, coal particles smaller than 63  $\mu\text{m}$  may also pose a flotation problem due to the low probability of adhesion between particles and bubbles, and coal particles larger than 500  $\mu\text{m}$  are not effectively treated using the froth flotation method.

## 4. RESULTS AND DISCUSSIONS

The froth flotation method with particle sizes ranging from 125-63  $\mu\text{m}$  and an impeller speed of 2500 rpm is an effective way to increase the calorific value of raw coal from 4806 cal/gm to above 5000 cal/gm for treated coal. Additionally, the carbon content of the Dedo coal deposit can be increased to a level suitable for use as an energy source in cement and steel industries.

### 4.1. Optimized parameters

This study aimed to understand the effects of particle size and impeller speed on coal flotation in the study area. Eight experiments with two replications were conducted to gain an overall understanding of these impacts. Particle size and impeller speed were the only variables that could be optimized during the flotation process. The optimization of these working parameters was based on the one variable at a time (OVAT) method in this investigation. The maximum coal concentration efficiency was measured as the response, along with impeller speed and particle size as the main factors. At the optimized condition, the maximum yield of floated coal obtained was 67%, as summarized in Table 3.

Table: 3. Optimum values for floatation of the coal

No	Parameters	An optimized value of coal
1	Feed rate(g)	100
2	Particle size( $\mu\text{m}$ )	-125+63
3	Impeller speed(rpm)	2500
4	Yield of concentrate (%)	67

### 4.2. The flotation results

As shown in Figure 8A, coal particle flotation was observed following the addition of kerosene collector. Large bubbles formed, but the particles did not attach to the surface of the oily bubbles. However, after the addition of N-octanol as a frother and floating for approximately 5 minutes, the bubbles stabilized and became smaller in size, as shown in Figure 8B. Additionally, the particles of the coal attached to the bubbles. The filtered concentrate (foam) was then prepared and dried in an oven at 80°C for around 3 hours before being taken for further analysis using the proximate analysis method, as illustrated in Figure 8C.



Figure 5: The procedures for froth flotation and the resulting coal particles.

### 4.3. Coal quality improvement

The quality of coal was improved after beneficiation (froth flotation) compared to that was before beneficiation. In this study, quality of coal before beneficiation, that means the moisture content 13.63%, volatile matter 33.34%, ash 25.66%, sulfur 0.36%, calorific value 4806 cal/gm, and after beneficiation moisture content 11.06 %, volatile mater 25.63%, ash 20.28 %, sulfur 0.25%, calorific value 5029.38 cal/gm . Therefore, the quality of coal was improved since, the moisture content, ash content and sulfur were reduced and calorific value was increased after beneficiation (froth floatation).

Table: 4. The proximate, sulfur, fixed carbon and calorific value results

Area	raw/treated Sample	Number of samples	Proximate results (%)			Sulfur content (%)	Fixed carbon content (%)	Calorific value
			ash content	volatile content	moisture content			
Dedo coal deposit	raw	1	25.66	33.45	13.63	0.36	35.08	4806 cal/gm
	treated	1	20.28	25.63	11.06	0.25	35.21	5029.38 cal/gm

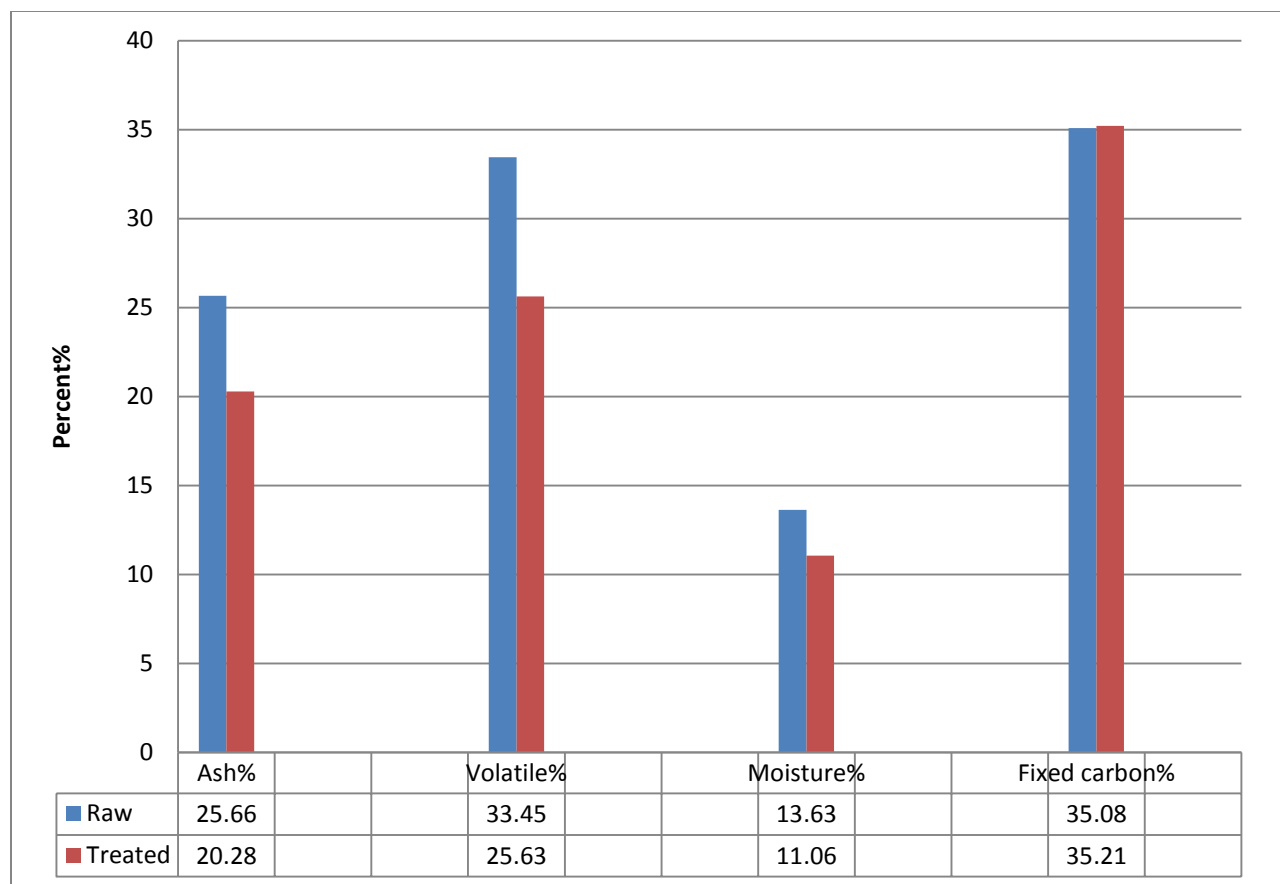


Figure 6 : The proximate analysis of raw and treated coal sample.

#### 4.3.1. The determination of moisture content amount

The moisture content of raw coal is 13.63%, while the moisture content of treated coal is 11.06%, as indicated in Figure 9. The raw coal has a relatively higher moisture content compared to the treated coal. A higher moisture value suggests lower carbon content, which leads to lower heating value and higher costs for transportation and storage (Wakuma and Assaba, 2017). The applied flotation technique decreased the moisture content, as shown in Figure 9.

#### 4.3.2. The determination of amount ash content

The ash content of the raw coal is 25.66%, while the ash content of the treated coal is 20.28%, as stated. An increase in ash content leads to a reduction in burning capacity, affects combustion efficiency, increases handling cost, and results in larger slagging. The ash content and its behavior at high temperatures affect the design and type of ash handling system employed in the coal-utilization process. At high temperatures, coal ash becomes sticky and eventually forms molten slag. The increase in ash content in coal leads to a decrease in quality or rank due to the higher volumes of impurities, which reduce coal efficiency. The ash content of the Dedo treated coal sample was highly reduced after treatment by approximately 5.38%. This indicates that the treated coal sample can be ignited easily and is reactive in combustion.

#### **4.3.3. The determination of volatile matter**

Figure 9 shows that the volatile matter for the raw coal sample is 33.45%, while for the treated coal, it is 25.63%. A higher volatile matter in coal indicates a lower rank of the coal. An increase in volatile matter results in an increase in the quantities of combustible gases, which in turn decreases the amount of fixed carbon and ultimately reduces the heating value of the coal.

#### **4.3.4. The determination of fixed carbon**

Fixed carbon is a rough estimate of the heating value of coal. Figure 9 shows that the fixed carbon content of the raw coal sample is 35.08%, while for the treated coal, it is 35.21%. The raw coal sample has a lower fixed carbon content than the treated coal, indicating that the lower carbon content significantly affects the heating efficiency of the coal. The lower amount of fixed carbon is due to the high ash, volatile matter, and moisture content of the coal. An increase in fixed carbon content results in an increase in heating value and a decrease in ash content, which is observed after beneficiation.

## **5. CONCLUSIONS AND RECOMMENDATIONS**

### **5.1. Conclusions**

This project focused on investigating the flotation response of Dedo coal deposit using froth flotation techniques. The objective was to enhance the flotation of coal particles with a more hydrophilic nature, such as lignite and/or lignite to bituminous, and to improve the quality of fine coal particles by reducing impurity contents, such as ash, mineral matter, and sulfur resources. Additionally, the effects of particle size and impeller speed on coal flotation were identified.

The findings of this study revealed that the flotation performance can be greatly impacted by the size of coal particles and the speed of the flotation impeller. It is important to note that aside from coal particle size and flotation impeller speed, other factors such as solid percentage, air flow rate, collector type and dosage, frother type and dosage, pH of coal slurry, and conditioning time can also affect the flotation process. However, these effects were not investigated in this project. The negative impacts of these factors can be managed by altering the processing mechanisms.

The quality of coal was enhanced in this study after beneficiation, resulting in an increase in calorific value from 4806 cal/gm for raw coal to above 5000 cal/gm for treated coal. This suggests that impurity contents such as ash, mineral matter, and sulfur resources were reduced, and the calorific value of coal was increased by employing successful froth flotation techniques. Therefore, it can be inferred that the conduct of this project led to an increment in carbon content of the Dedo coal deposit, making it suitable as an energy source in cement and steel industries.

### **5.2. Recommendations for future project**

This study focused on investigating the flotation response, enhancing coal quality, and identifying the effects of coal particle size and flotation impeller speed only. It is recommended to investigate the influence of other factors such as solid percentage, air flow rate, collector type and dosage, frother type and dosage, pH of coal slurry, and conditioning time. In this study, N-octanol frother was utilized to generate a significant amount of small air bubbles, thereby increasing the surface area of air introduced into the flotation machine during coal flotation. Kerosene collector created conditions for the attachment of hydrophobic particles to air bubbles and the recovery of such particles in the froth product. In the future, researchers can interchangeably use methyl isobutyl carbinol (MIBC) instead of N-octanol and diesel oil instead of kerosene during flotation. Additionally, it is recommended to use teetered bed separators or reflux classifiers in combination with flotation columns to recover coarse coal particles, as it is effective in recovering coal up to approximately 0.35 mm.

## REFERENCES

- Abkhoshk E, Kor M, Rezai B.,2010. A study on the effect of particle size on coal flotation kinetics using fuzzy logic. *Expert Syst Appl* 37:5201–5207
- Alemayehu, T., Woldu, Z., & Tsegaye, A.,2015. Coal geology and its application in Ethiopia: an overview. *Journal of Geology & Geophysics*, 4(3), 1-6
- Arnold BJ, Aplan FF.,1989. The hydrophobicity of coal macerals. *Fuel* 68:651–658
- Behera, Soumit K.,2022. Assessment of carbon sequestration potential of tropical tree species for urban forestry in India. *Ecological Engineering* 181: 106692
- Campbell, John Asa Lewis.,1969. An electrokinetic study of bituminous coal froth flotation and flocculation. The Pennsylvania State University
- Chen, Jiarui, Wonder Chimonyo, and Yongjun Peng.,2022. Flotation behaviour in reflux flotation cell—A critical review. *Minerals Engineering* 181 : 107519
- Cheng, G., Shia, C.L., Liuc, J.T., Yand, X.K.,2016. Bubble-distribution measurement in a flotation column. *International Journal of Coal Preparation and Utilization*, 36: 241-250
- Dejene Y.,2004. The Utilization of Indigenous Coal as Energy Substitute in Cement Industry. M.Sc.Thesis, Addis Ababa Institute of Technology, Chemical and Bio-Engineering (Process Engineering stream)
- Demoze EA.,2007. Utilization of Coal in Metal Industries (In Case of Akaki Metal Products Factor). MSc, Thesis, Addis Ababa University, Department of Environmental Engineering
- Dey, Shobhana.,2012. Enhancement in hydrophobicity of low rank coal by surfactants—A critical overview. *Fuel Processing Technology* 94:151-158
- Di Gianfrancesco, A.,2017. Worldwide overview and trend for clean and efficient use of coal. *Materials for Ultra-Supercritical and Advanced Ultra-Supercritical Power Plants* 643-687. Slurry
- Eliseu, Geraldo Conde .,2019. Effects of recirculated water on the flotation of Kushiro and Mozambique Coals
- Garfinkel, Harold, Michael Lynch, and Eric Livingston.,1981. The work of a discovering science construed with materials from the optically discovered pulsar. *Philosophy of the social sciences* 11.2: 131-158
- Ghaffari, S.,2019. Review of superoleophobic surfaces: Evaluation, fabrication methods, and industrial applications. *Surfaces and Interfaces* 17: 100340

Hailu, Ashebir Dingeto, and Desta Kalbessa Kumsa.,2021. Ethiopia renewable energy potentials and current state. *Aims Energy* 9.1: 1-14

Hower JC, Frankie KA, Wild GD, Trinkle EJ .,1984. Coal microlithotype response to froth flotation in selected western Kentucky coal. *Fuel Process Technol* 9:1–20

Hunde, S.,2016. Overview of the geology and mineral potential of Ethiopia. *Journal of African Earth Sciences*, 116, 22-35.

Imbabi, Mohammed S., Collette Carrigan, and Sean McKenna.,2012. Trends and developments in green cement and concrete technology. *International Journal of Sustainable Built Environment* 1.2: 194-216

Itay, Michael, Cavan R. Hill, and David Glasser.,1989. A study of the low temperature oxidation of coal. *Fuel Processing Technology* 21.2: 81-97

Jones, R. E., and D. T. A. Townend.,1949. The oxidation of coal. *Journal of the Society of Chemical Industry* 68.7: 197-201

Katalambula, Hassan, and Rajender Gupta.,2009. Low-grade coals: A review of some prospective upgrading technologies. *Energy & Fuels* 23.7: 3392-3405

Klimpel, R. R.,1995. The Influence of Frother Structure on Industrial Coal Flotation, High efficiency Coal Preparation Society for Mining, Metallurgy, and Exploration, Littleton, CO, pp. 141-151

Korobetskii, I. A., N. V. Balabanova, and A. N. Zaostrovskii.,1990. A new approach to the investigation of coal. *Fuel Processing Technology* 24: 453-458

Laurila H, Karesvuori J, Tiili O.,2002. Strategies for instrumentation and control of flotation circuits, *Mineral processing plant design, practice and control*. Vol. 1, 2174-2195

Lynch AJ, Johnson NW, Manlapig EV, Thorn CG.,1981. *Mineral and coal flotation circuits—their simulation and control*. Elsevier, Amsterdam, pp 53–56

Matis, K. A., G. P. Gallios, and K. A. Kydros.,1993. Separation of fines by flotation techniques. *Separations Technology* 3.2: 76-90

Majumder, A. K., and J. P. Barnwal.,2011. Processing of coal fines in a water-only cyclone. *Fuel* 90.2: 834-837

Moxon, N. T., 1993. Chemical variables in coarse coal flotation. *Coal preparation* 12.1-4 :15-26

Nagaraj, D. R., and S. A. Ravishankar.,2007. Flotation reagents—A critical overview from an industry perspective. *Froth flotation: A century of innovation* 375-424

Olson, T. J., and F. F. Aplan.,1984. The floatability of locked particles in a coal flotation system. Proc. 2nd Int. Congr. Appl. Mineralogy in Min. Industry 367

International Journal of Mineral Processing Özbayoğlu, Gülhan.,1987. Coal flotation. Mineral Processing Design 76-105

Özbayoğlu, G., T. Depci, and N. Ataman.,2009. Effect of microwave radiation on coal flotation. Energy Sources, Part A 31.6: 492-499

Polat, Mehmet, Hürriyet Polat, and Subhash Chander.,2003. Physical and chemical interactions in coal flotation. 72.1-4: 199-213

Pusz, S.,1997. Interactions between organic matter and minerals in two bituminous coals of different rank. International journal of coal geology 33.4: 369-386

Ramudzwagi, M., N. Tshiongo-Makgwe, and W. Nheta.,2020. Recent developments in beneficiation of fine and ultra-fine coal-review paper. Journal of Cleaner Production 276: 122693

Rao, T. C., Govindarajan, B., and Barnwal, J. P.,1995. A Simple Model for Industrial Coal Flotation Operation, High-Efficiency Coal Preparation, Society for Mining, Metallurgy, and Exploration, Littleton, CO, pp. 177-185

Rao, S. Ramachandra.,2013. Surface chemistry of froth flotation: Volume 1: Fundamentals. Springer Science & Business Media.

Sonmez Ibrahim, Cebeci Yakup.,2006. Performance of classic oils and lubricating oils in froth flotation of Ukraine coal, Fuel 85, pp. 1866-1870

Tian, Q., Y. Zhang, G. Li, and Y. Wang.,2017. Application of carboxylic acid in low-rank coal flotation. International Journal of Coal Preparation and Utilization 39 (1):44–53

Wakuma B., Assaba B.,2017. Physicochemical characterization of coal and its alternative use as a source of energy (in case of Yayo coal mining industry. *J. Environ. Sci. Toxicol. Food Technol. (IOSR-JESTFT)* ;11(5):44–50

Whelan, P. F., and Brown, D. J.,1956. Particle-Bubble Attachment in Froth Flotation Bulletin of the Institute of Mining and Metallurgy, No. 591, pp. 181-192

Williams, M. C., and D. W. Fuerstenau.,1987. Simple flotation method for rapidly assessing the hydrophobicity of coal particles. *Int. J. Miner. Process.:(Netherlands)* 20.1/2

Woodbum ET, Wallin PJ.,1984. Decoupled kinetic model for simulation of flotation networks. *Trans Inst Min Metall (Sect C Miner Process Extr Metall)* 93:C153–C161

Xia, W., Ni, C., Xie, G.,2016. Effective flotation of lignite using a mixture of dodecane and 4-dodecylphenol (ddp) as a collector. *International Journal of Coal Preparation and Utilization*, 36: 262-271

Yohannes, T., Tilahun, M., & Nigussie, A.,2019. Coal potential of Ethiopia: a review. *International Journal of Mining Science and Technology*, 29(2), 235-242