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ADDIS ABABA INSTITUTE OF TECHNOLOGY
CENTER FOR ETHIO-MINES DEVELOPMENT (CEMD)

BENEFICIATION AND CHARACTERIZATION TECHNIQUES OF COAL IN THE WESTERN REGION OF TARCHA ZURIA WEREDA, SOUTHERN ETHIOPIA

A MASTER’S RESEARCH PROJECT SUBMITTED TO THE CENTER FOR ETHIO-MINES DEVELOPMENT, ADDIS ABABA INSTITUTE OF TECHNOLOGY, ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING IN MINERAL ENGINEERING.

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May 2025
Addis Ababa, Ethiopia

DECLARATION

I, **Mr. Daniel Kassaye G/Giorgis** (**GSR/8290/15**), hereby declare that this MSc research project titled ***"Beneficiation and Characterization Techniques of Coal in the Western region of Tarcha Zuria Wereda, Southern Ethiopia"*** conducted by me under the advisor of **Dr. Zekarias Gebreyes Eticha** is my original work and has not been submitted to any other institution for the award of any academic qualification. The proposal's content has not been plagiarized and the works of other researchers have been appropriately acknowledged.

Candidate's Name **Mr. Daniel Kassaye G/Georgis**

Signature: ______________________ Date, **May 2025**

APPROVAL PAGE

This is to certify that is to certify that we have read this MSc research project ‘‘Beneficiation and Characterization Techniques of Coal in the Western region of Tarcha Zuria Wereda, Southern Ethiopia’’ and in our opinion; it is fully adequate, in scope and quality, as a Master's research project for The Degree of Engineering in mineral engineering

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Dr. Zekarias Gebreyes Eticha Signature_________________ Date: - May, 2025

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Dr. Abubeker Yimam) Signature__________________Date: - May, 2025

Acknowledgment

With no trace of doubt in my mind, I believe GOD deserves to get the first praise I wish to extend since he gave me all the courage, devotion, and knowledge to complete my project work successfully. Then, I want to pass my deepest gratitude to my adviser Dr. Zekarias Gebreyes (PhD) for the continuous advice & support you provided me with, until the completion of my project work. You have shown me how crucial advice becomes in making any project work more precise, rich in scientific proofs & above all the beauty of the fact that, many minds are always better than one.

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Finally, my thanks go to all my beloved family who were always helpful & confident in me & all my classmates, I will be missing when this project work is over.

ABSTRACT

Coal stands as the most plentiful and extensively found fossil fuel. Thanks to advanced methods, it can be extracted, moved, and stored efficiently and economically. The global trade of coal is experiencing consistent growth, accompanied by intense competition regarding supply and pricing. Nevertheless, the future commercial viability of coal hinges on its environmental sustainability, particularly on the ability of the power generation sector to minimize sulfur and other harmful emissions. This research examines the extraction methods employed at the Tarcha coal deposit located in Tercha Zuria Wereda, Southern Ethiopia. It utilizes a wet extraction technique to evaluate flotation responses and optimize key factors such as yield percentage and ash content. The primary goal of the study is to enhance the quality of coal by refining flotation processes and minimizing impurities. Laboratory experiments are conducted with varying particle sizes and different ratios of collector to frother in the froth flotation process. The results indicate that the highest coal recovery yields are achieved at a collector-to-frother ratio of 8:4, while also assessing how these variables affect ash content. The data reveal a clear trend of increasing ash content as particle size decreases, highlighting the importance of maintaining specific parameter ranges to optimize yield. Ultimately, this project offers valuable insights that could support local mining operations, particularly the ET-Mining Development Company, which is actively involved in job creation and community development initiatives. The outcomes of this study may also aid Ethiopia in meeting its domestic coal needs, potentially decreasing its dependence on imported coal as the nation advances its coal resource development.

Keywords:- Froth flotation, Particle size, Ash content, Coal deposit, Collector, Frother

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List of Abbreviation

ET-Mining ……………………………….. Ethiopian Mining

EPM ………………………………………. Equal Particle Misplacement

BC………………………………………… Before Christ

ASTM……………………………………... American Standard of Testing Method

ADMFB …………………………………… Air Dense Medium Fluidized Bed

DMS……………………………………….. Dense Medium Separation

UCC……………………………………….. Ultra Clean Coal

AFC………………………………………. Ash Free Coal

CHAPTER ONE

1. BACKGROUND OF THE STUDY

1.1 Introduction

The research area is situated within the Dawro Zone of the Southwest Region, including the town of Tarcha and its adjacent regions. Its geographic coordinates span from 7°10′0″N to 7°11′0″N in latitude and from 37°13′0″E to 37°14′0″E in longitude. This area is approximately 507 kilometers away from Addis Ababa and is accessible via the asphalt road connecting Addis Ababa to Jimma, which leads to Tarcha Road. The location is illustrated in Figure 1 (Girma and Teshome 2023).

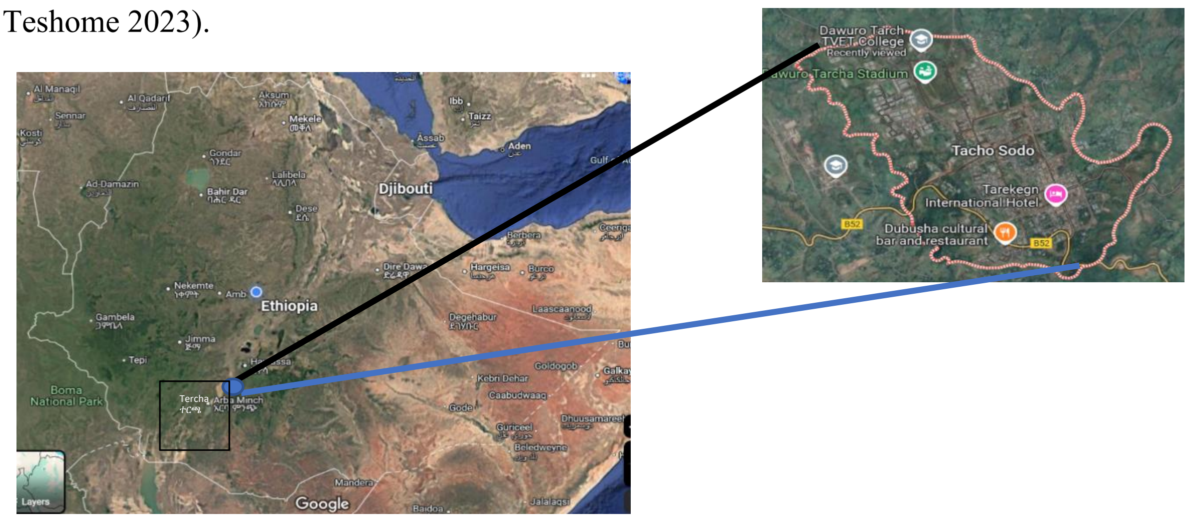


Figure 1 : Location Map of Tercha Coal Mine [36]

Tarcha coal exhibits a light dark color, as illustrated in figure 2, figure 3, and is generally found at the lower sections of slopes, where its strength is comparatively diminished. The coal unit is overlain by trachyte flow, and the study area of the coal quarry sites reveals the presence of vertical and sub-vertical fractures, as well as lamination and bedding within the coal seam.

Figure 2 : Tarcha Coal Lithological units & layers

Figure 3 : , Tarcha coal open-pit mining site

Coal is the most abundant and extensively used reactionary energy. Its extraction, transportation, and storage can be conducted cost-effectively and efficiently through modern techniques. The market for coal is characterized by intense competition regarding supply and pricing, and the global coal trade is experiencing rapid growth(Upgupta and Singh 2018). Nevertheless, the future commercial development of coal will largely hinge on its environmental acceptability, particularly the ability of the power generation sector to mitigate sulfur and other harmful emissions. Although emissions have been significantly reduced due to the adoption of low-sulfur coals and the implementation of advanced flue gas desulfurization technologies in conventional power plants, there remains limited potential for further improvement (Demirbas 2007). The process of coal conformation varies slightly across different regions, told by the specific foliage and environmental conditions, yet the beginning medium remains the same. Coal formation occurs in two main phases: peatification and coalification. Peatification is primarily driven by bacterial activity, while coalification is influenced by the increased temperature and pressure resulting from the burial of organic matter.Vegetation in marshes and wetlands, including ferns, shrubs, vines, trees, and algae, eventually dies and collects on the surface. At first, this organic material is broken down by bacteria, producing carbon dioxide and methane. As the factory matter becomes buried, it's shielded from the air. This process of burial and accumulation can take place over time(Shan, Varbanov, and Pan 2014).

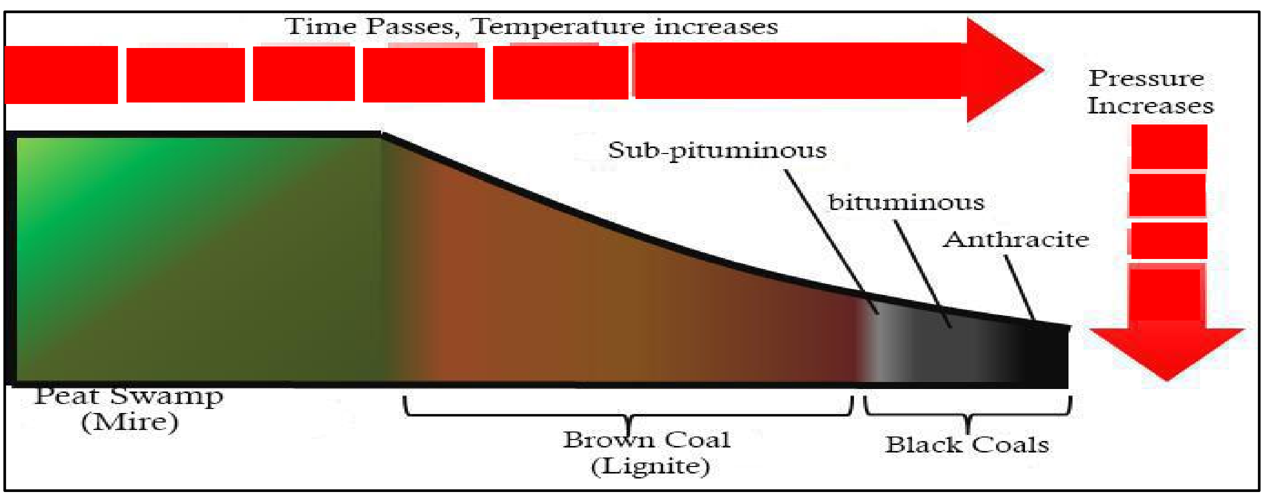


Figure 4 : Coal Process of Transformation (Alpern and DeSousa, 2002)

Coal is one of the primary energy sources globally. This black fuel was first discovered in China around 1500 BC, marking its inaugural use in human history(Zhao et al. 2008). The extensive use of coal resources and large-scale extraction did not become a global phenomenon until the Industrial Revolution in the 18th and 19th centuries. During this period of technological advancement, coal emerged as the main fuel source for emerging industries. Consequently, the coal market experienced substantial growth, which has continued over time, albeit with occasional minor disruptions (Chandran Govindaraju and Tang 2013).

It continues to play a crucial role in the global energy landscape. As of 2015, it represented 41% of global electricity generation, 29% of primary energy consumption worldwide, and 44% of industrial output on a global scale(Wang et al. 2016). In the coming two decades, coal is expected to maintain its significance owing to its affordability and extensive accessibility (Bian et al. 2017).

Ethiopia's coal reserves are estimated to be approximately 300 million tons, with a broad distribution across various regions. Notable locales include the northern Chilga receptacle, the southwestern areas of Delbi-Moye, Yayo(comprising Wittete, Achibo, Sombo, Dabaso, and Kumbabe), as well as the Nejo and Arjo basins, and the central Ethiopian table, which features the Mush vale and Wuchale receptacle. still, despite the substantial vacuity of coal, it's marked by significant contaminations, including elevated situations of ash and sulfur, along with a veritably low carbon content and spicy values that align with ASTM-D-388 norms and the degree of metamorphism(Usman et al. 2022a).

At present, small-scale producers fulfill 66% of the coal requirements for the cement industry, which is the primary consumer. Effective coal mining allows the nation to replace substantial quantities of imported coal, leading to a decrease in significant foreign currency expenditures. Domestic coal production not only results in cost savings and job creation but also facilitates more efficient transportation and diminishes dependence on imports. This, in turn, helps to conserve valuable foreign currency and provides the country with a competitive advantage(Ahmed 2016).

Throughout thousands of years, several meters of partially decomposed plant material, referred to as peat, have accumulated. The deep burial of this peat leads to the expulsion of water and various chemicals due to increasing pressure, resulting in the formation of lignite, which is considered the lowest grade of coal.

As burial continues, the temperature and pressure increase, transforming this low-quality lignite into higher-quality "Black Coals." Initially, lignite is converted into sub-bituminous coal, followed by the production of bituminous coal as the next stage in this process.(Ristinen and Kraushaar 2006). The highest quality anthracite coal follows. Due to these transformations, the coal becomes denser and has reduced moisture and chemical content, leading to an increased carbon concentration.

Low-grade coals present challenges in terms of cleaning due to their low washability, rendering them less effective with contemporary coal beneficiation techniques. Over the past few decades, there has been a noticeable shift in preference for low-grade coal, particularly in countries such as China, India, and the United States.. (Ryberg et al. 2015).

The characteristics of low-grade coals vary based on their geographical origin, as they do not possess uniform traits. Unlike high-grade coals, the use of low-grade coals in industrial applications is often discouraged due to various issues, such as their low carbon content and the presence of substantial mineral impurities that contribute to ash formation(Dash et al. 2015).

Although Ethiopia possesses coal resources, it currently relies on imports of processed coal from countries such as South Africa. The cement factories in Ethiopia utilize this imported coal, but Ethiopian-Mining Development Company aims to replace over 75% of these imports with locally sourced processed coal.

With a production capacity of 150 tons per hour of refined coal and 3,600 tons per day of coal products, the potential impact of this project is substantial. The findings and results will significantly aid the country in meeting its internal coal demand while Also enhancing the company's profitability. Furthermore, the company is committed in financing activities of social

Responsibility, having supported community development initiatives by constructing two health centers and a school, which collectively generated over 300 jobs during the construction phase. Additionally, the factory has created approximately 400 jobs for residents. This project not only provides new insights into coal recovery and grading but also indirectly supports both the nation and the local communities surrounding the Tarcha Coal mine.

The mudstone-coal-shale and sandstone-coal-shale facies represent the most favorable coal reserves. While Ethiopia possesses coal coffers, it's essential to estimate the most effective birth styles for unborn application. Among the various techniques in mineral processing, froth flotation stands out as a widely used separation method . This article investigates the extraction processes employed in a low-grade coal mine situated in Tercha Zuria Wereda, focusing on the wet extraction method. The study highlights the considerable financial advantages that can be achieved by optimizing various existing operations.

1.2 Statement Problem

Lack of effective Coal processing plants and latest equipments for flotation processes poses major obstacles in coal benefication in Ethiopia. The majority of the coal mines in our nation produce low-quality coal(Wolela 2007), therefore it would be wise to boost demand for processing low-grade coal to raise its grade by employing the froth flotation method right once. To improve the coal grade and recovery, this study used froth flotation techniques to determine the flotation response of the Tarcha coal deposit and search for new possibilities.

1.3 Objectives of the study

1.3.1 General objective:-

The general objective of this research is upgrading low grade Tarcha Coal through flotation, to identify flotation response & to indicate the optimized characterization result of the Tarcha coal deposit in terms of percentage of yield and ash content.

1.3.2 Specific objectives

- To Investigate the property of the coal after floatation
- To optimize the coal property in terms of yield percentage and ash content
- To improve the flotation of coal particles which have a more hydrophilic behavior during the coal beneficiation process.
- To enhance the quality of the coal by lowering contaminants.

1.4 Significance and Limitation of the study

In the Omo-Gibe River basin located in southern Ethiopia, the Tarcha coal deposit is currently being extracted through open-pit mining methods to harness energy resources. This deposit lies beneath the Omo Trachyte flow. Nonetheless, the mines are facing significant challenges related to slope instability.(Abebay et al. 2024a). Numerous mining companies and researchers have employed a range of mitigation strategies and laboratory analysis initiatives to tackle the challenges posed by open-pit coal mine quarries and to enhance stability at mining locations.

Nevertheless, the issue continues to exist, presenting significant risks to mining operations in the region. The instability of the Tarcha coal deposit has been attributed to factors such as soil saturation and the height and angle of the open-pit coal mines. To address these challenges, several mitigation strategies have been employed, including geometric modifications such as lowering the slope angle, reducing the height of the slopes, and incorporating benching techniques, all of which are believed to enhance slope stability considerably. Despite all those efforts has been made the wide discovery in enhancing the coal quality is not practiced. Employing froth flotation techniques will serve as a mechanism to effectively capitalize on the opportunity. The outcomes of the project will be utilized to enhance profitability in terms of both Recovery (yield quantity) and Coal quality (grade). Experimental evidence indicates that alterations in coal particle size and impeller speed in laboratory settings can lead to substantial variations in the flotation process results(Abebay et al. 2024b).

The outcomes of this project will be significant and beneficial for several major mining companies operating in the Tarcha Coal mining region. A prime example is the Ethiopian-Mining Development Company, which is actively involved in coal extraction within the Dawero Zone of Tarcha Zuria Wereda. Working to replace imported coal demand.

1.5 Scope of the Study

This project's Scope or boundary is bounded in laboratory work space and operates focused on bringing breaking findings in Tarcha coal minerals characterization & froth flotation of this sample to bring about improvements in terms of ash content & yield amount (Recovery).

1.6 Outline of the project

This study focuses on the extraction and characterization of coal from the Tercha Zuria wereda Southern Ethiopia and the subsequent chapters address this topic in detail.

Chapter 1: Provides an introduction, Location of Tarcha Coal mine and discusses the natural formation of coal, and outlines the coal deposits available in Ethiopia. It also includes a problem statement, objectives, significance, and the scope of the research.

Chapter 2 : Geology of the study area with detailed Lithological and Soil description.

Chapter 3 : Presents a comprehensive literature review, which includes an analysis of existing gaps in the current knowledge.

Chapter 4 : Chemical reagents, lab instruments used as well as the raw materials and method of data collection discussed in detail.

Chapter 5 : the results were discussed thoroughly.

Chapter 6 : Conclusion and recommendation were forwarded.

CHAPTER TWO

2. GEOLOGY

2.1 Regional geology

The Ethiopian physiography comprises expansive plateaus in the northwest and southeast, the main Ethiopian Rift Valley, and the Afar Depression (Tefera M., Chernet T., Haro W.,Teshome N., Woldie K., and Sarvéy Y.1996). Along the margin of the southwestern Ethiopian Plateau, the main Ethiopian Rift hosts a thick pile of flood basalts with alkaline to tholeiitic affinities and minor rhyolites, which were deposited from the Eocene to the Middle Miocene (Woldegabriel G., Aronson J. L., and Walter R. C.,1990).

According to Wolela (Wolela A.,2007), the Dilbi-Moye and Gojeb-Chida Basins and other minor grabens on the southwestern plateau, which contain coal and oil shale deposits, formed in relation to the structural evolution of the western branch of the African rift system. The grabens were likely governed by the NNE–SSW/NS trending Ashange rift, the northern continuation of the western rift (Wolela A.,2007). The sediment on the lower basalt, dated to 30.45 MPa, unconformably overlies the sediment on the upper on of the basin includes a Precbasalt at 10.98 MPa (Wolela A.,2007).

The Jimma map sheet displays the Tarcha area, characterized by Omo trachyte flows exposed in the Omo-Gibe River basin valley. This basin extends from Kenya to Ethiopia and is situated amidst significant rift systems such as the main Ethiopian Rift, the Chew Bahir Rift, and the Lake Turkana Rift (Davidson A.,1983). The geological compositiambrian crystalline basement, Tertiary volcanic rocks, Quaternary alluvial sediments, and volcanic flows (Davidson A.,1983). The Cenozoic rocks in the southwestern Ethiopian area provide evidence of both pre- and postrift successions. Additionally, the region is predominantly covered by Tertiary lava flows, pyroclastic flows, pyroclastic fallouts, ash flows, and minor Quaternary ashfalls and alluvial deposits.

These geological formations form a thick layer of basalt and felsic rocks, with basalt being dominant in the lower sections. Additionally, there are minor Quaternary ashfalls present in the area, adding to the geological complexity of the region (Tefera M., Chernet T., Haro W.,Teshome N., Woldie K., and Sarvéy Y.1996). The Tarcha area is a geologically rich and diverse landscape with a complex history of volcanic activity and tectonic movements.

According to previous studies, this area flow pattern is from the pre-Oligocene age and consists of lower volcanic flows, Omo trachyte flows, lower basalt flows, lower trachyte flows, and lower pyroclasts (Tefera M., Chernet T., Haro W.,Teshome N., Woldie K., and Sarvéy Y.1996, Kazmin V.,1973). The emplacement of middle basalt and trachyte flows may have occurred during the Oligocene. The initial volcanic activity in the region can be traced back to the Miocene–Pliocene epoch, as detailed by Feleke (Feleke A.,2021), who offers an insightful overview of the area lithological composition, encapsulated in the subsequent summary. Lower basalt and lower trachyte flows are interpreted as older volcanic areas that can be linked to the Ashanghi Formation. In contrast, the middle and middle trachyte flows are interpreted as fissure eruptions that can be associated with the Aiba Formation.

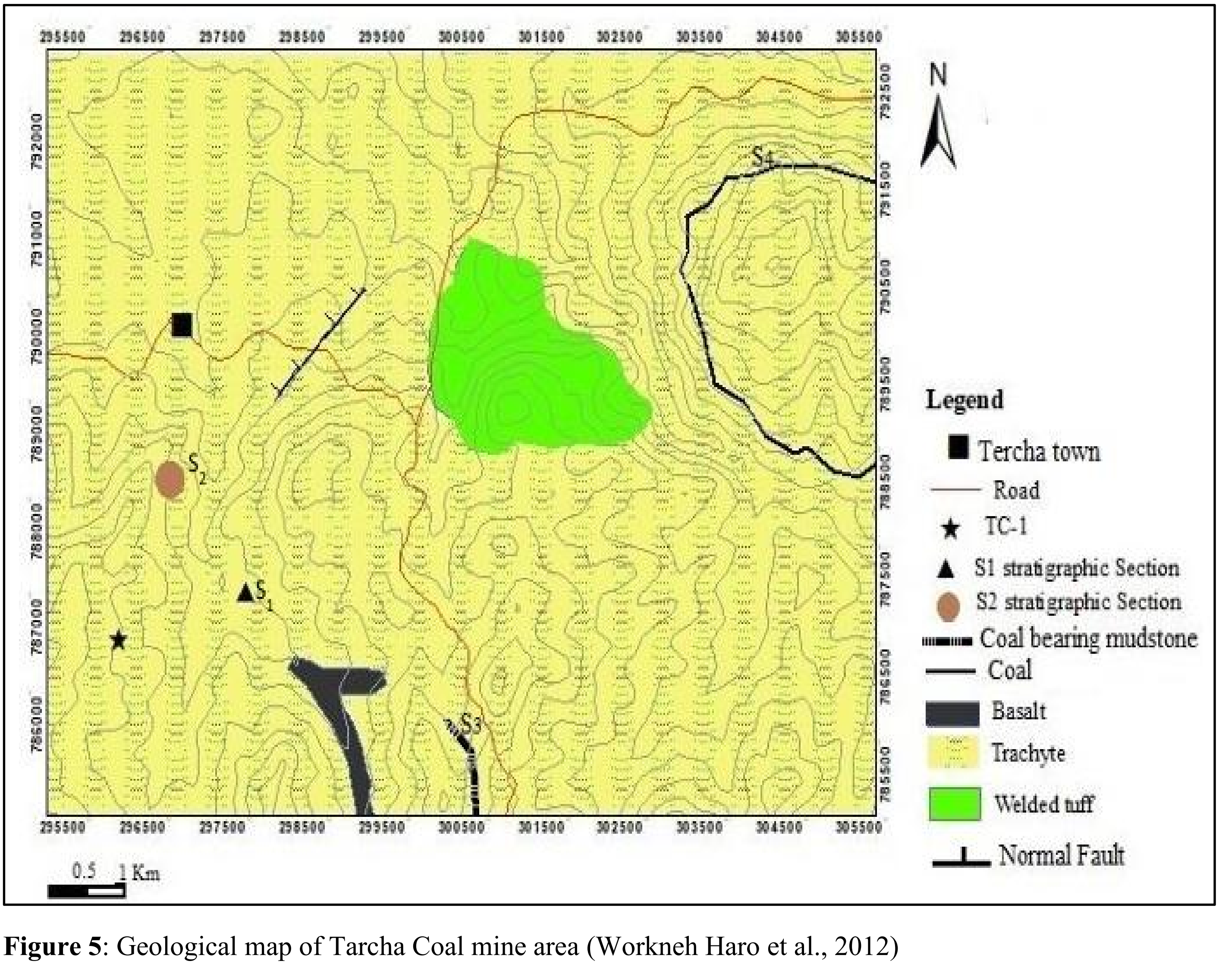


Figure 5: Geological map of Tarcha Coal mine area (Workneh Haro et al., 2012)

2.2 Local geology

Tercha is a subsheet within the Jima map sheet. Geologically, it is covered with trachyte flows, exposed in the Omo River Valley in the eastern part of the study area. These trachyte flows are also visible in the Gojeb River Valley near Chebera Churchura National Park, south of Felega Selam, southwest of the map area, and in the Wuki bro-Gera lowlands, containing coal layers north of Chida (Takele M. M.,2018).

East of Tercha and west of Gojeb town, the unit is mixed with weathered ignimbrite, showing a light gray color and medium-grained texture (Takele M. M.,2018). Northwest of Chida, this lower trachyte flow is intercalated with horizontal, often friable coal beds.

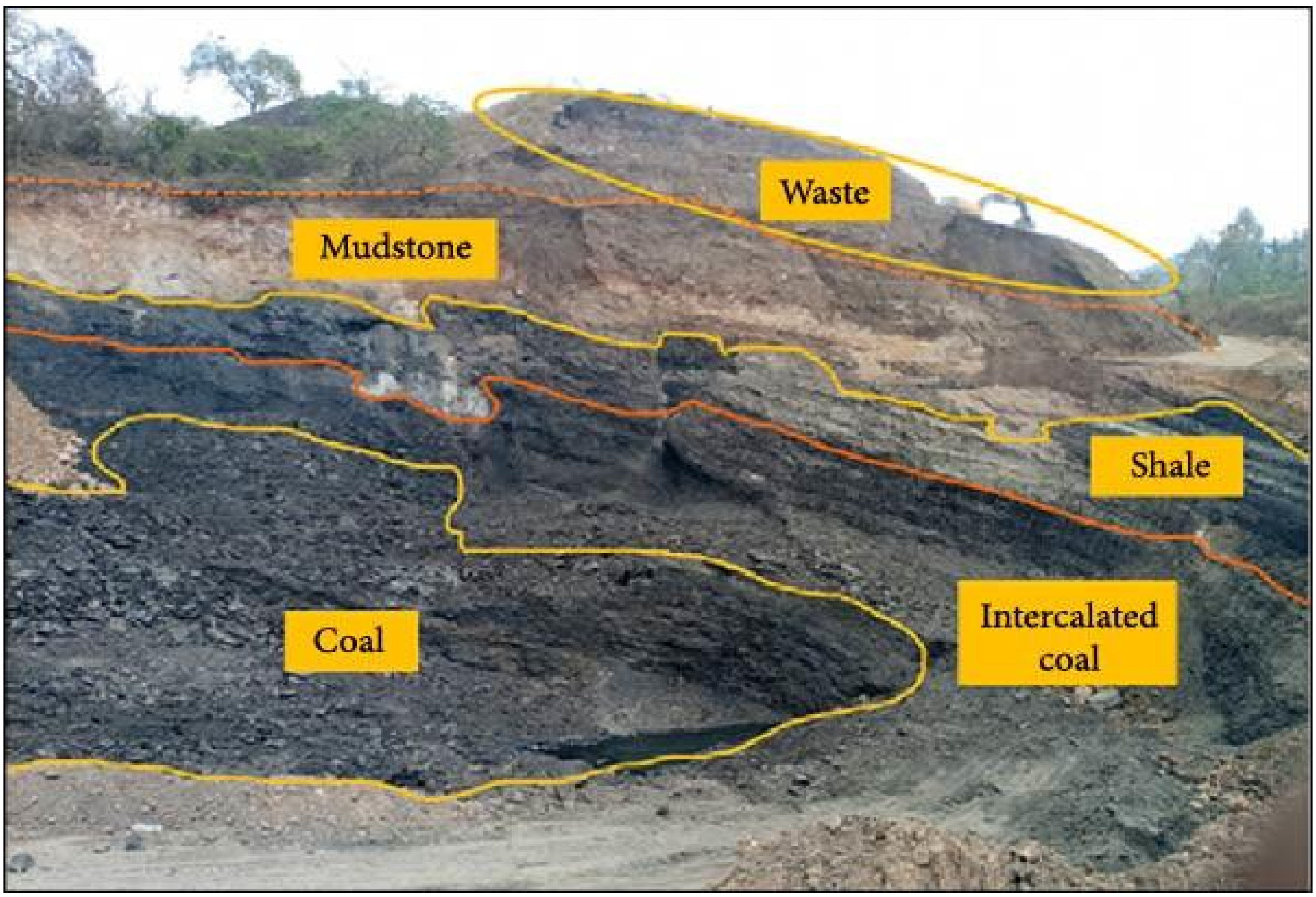


Figure 6: Local geological map of Tarcha Coal mine area (Takele M.M., 2018)

The major rock exposures found in the study area are summarized below.

2.2.1 Trachyte

This unit covers the uppermost sections of the coal quarries near the Baccire River. The material is fine- to medium-grained and massive, appearing light gray when weathered and dark gray when fresh. Thickness ranges from 2 to 7 m. These coal-bearing sediments are sporadically distributed, forming horizontal beds, with an overall thickness not exceeding 30 m. Most of the coal and coal-bearing sediments are surface deposits.

Figure 7: Trachyte unit exposed in the mine site, with light grey color, massive, no fractures, with fresh and weathered parts and, porphyritic texture(Mengistie, T. M. 2018).

2.2.2 Mudstone

Most sediments in the study area are surface deposits. The mudstone is fine- to medium-grained, ranging from friable to compact, forming horizontal bedding and generally breaking into small blocks while exhibiting intercalation with shale. The mudstone found at the bottom of the geological stratigraphy is highly compacted and exhibits higher strength.

Figure 8: Mudstone exposure with a reddish brown color (due to oxidation of iron) weathered , fine to medium grained and highly friable.(Mengistie, T. M. 2018).

2.2.3 Shale

This unit, intercalated with coal and mudstone, overlays the coal seam and characterized by its gray color, high friability, and fine-grained texture. It is found above the intercalated coal ranging in degree of compaction from fissile to compact units, forming horizontal bedding, and is very susceptible to sliding due to closely spaced fractures.

Figure 9: Shale unit with grey color, fine grained, weathered and fissile (Mengistie,T.M.2018).

2.2.4 Coal (Tarcha Coal)

The coal found in the study area is characterized by a light dark color and is typically located at the bottom of slope sections, where it is weaker in strength. Vertical and subvertical fractures, lamination, and bedding of the coal seam are observed in these quarry sites. It has low strength and a dull luster, with an average thickness of 3–5 m. Small bands are often observed within the coal. In each quarry section, the coal is horizontally bedded, but there is a minor dip in the sedimentary units exposed in the coal mining quarries. The overall thickness of the entire seam is generally thin, not exceeding 10 m in most cases.

Figure 10: Tarcha Coal rock sample, very lustrous, highly compacted, high strength and demonstrate sub conchoidal fracture (Mengistie, T. M. 2018).

2.3 Vertical Logs for Tarcha Coal Quarry

A vertical log section of a coal mine visually depicts the geological formations encountered during mining operations. Generated after describing the lithologic units and their thickness in the field, it includes various rock layers such as mudstone, shale, and coal seams, along with their respective thicknesses and depths exposed. This information is crucial for understanding the mine geology and structure, aiding in planning mining activities, determining coal reserves quality and quantity, and designing efficient mining methods.

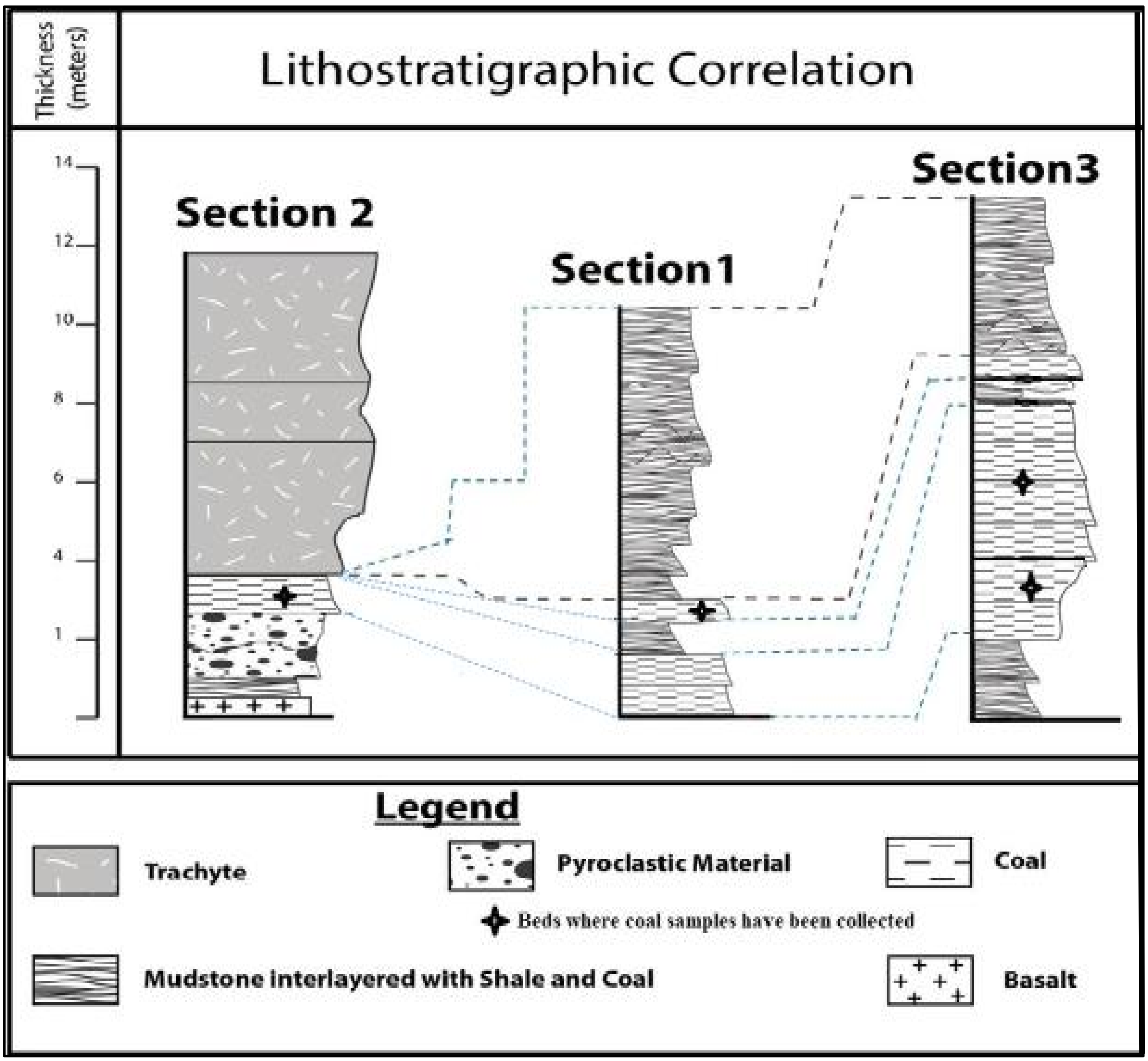


Figure 11: Lithostratigraphic correlation of stratigraphic sections, section 1, section 2 and section 3 (Workneh Haro et al., 2012)

2.4 Comparison of Tarcha coal with other Coal Deposits

Different coal deposits found throughout the world has different physical, chemical, depositional and value characteristics. This difference has its role in the use and commercial track. To make relative value of Tarcha coal with other deposits this resource is compared with the Indian Talchar and Jharia coal , Waterberg South Africa coal and other Ethiopian coals (Delbi-Moye, Yayu, Gojeb-Chida, Mush, Nejo, Wuchale, Chilga and Lalo-Sapo)

For this comparison calorific value (CV), fixed carbon (FC), ash content, nitrogen and sulfur are selected because they have vital roles to characterize the coal for utilization and impact on the coal. The selected results of deposits are the best results to mainly focus on their application and higher status. Tarcha coal has higher FC than Talcher coal and lower than Jharia Coal but relatively equivalent with other Ethiopian coals.

The ash value of Tarcha coal is higher than that of Jhaira coal and relatively lower than the Talchar coal. The CV of Tarcha coal is higher than Talchar and other Ethiopian coals but lower than Waterberg coal. The Talchar and Waterbeg coals are used for power plant project (Kumar et al., 2015; Makgato and Chirwa, 2017).

Tarcha coal samples have equivalent sulfur content with Indian Talchar coal but higher sulfur content relative to other Ethiopian coals. The great issue comes as the value of sulfur increases, the quality of the coal decreases and increasing the hazard. Tarcha coal has higher sulfur content than those of Gojeb-Chida and Moye coals, however, the difference is not that much. According to Wolela (2007) Yayu coal can be gasified to produce chemical fertilizers as its volatile matter and nitrogen amount is very good with high calorific value. The general increases and decrease of one parameter does not verify the other in parallel way hence coal is a very complex rock.

Table 1: Local Coal resource ultimate analysis (%) and calorific value (Kcal/Kg) results comparison. (Tarcha result (present study); other results (Wolela Ahmed, 2008).

Location	CV	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur
Mush Valley	4390	5.72	68.93	1.23	24.12	1.5
Nejo	4990	5.17	72.2	0.82	21.81	0.6
Gojeb - Chida	4080	6.44	73.54	1.28	18.74	0.4
Wuchale	3710	5.41	74.84	1.53	18.22	1.6
Moye	4920	5.34	80.22	2.27	12.17	0.4
Delbi	6580	5.5	66.1	1.11	27.29	0.6
Yayu	5788.9	4.2	69.4	1.2	25.2	1.65
Tercha	7300	5.43	81.14	2.48	11.14	0.46

Table 2: Local Coal resource proximate analysis results (%) comparison and calorific value (Kcal/Kg). (Tarcha result (present study); other results (Wolela Ahmed, 2008).

Location	Specific Locality	Moisture	VM	Ash	FC	CV	sulfur
Delbi - Moye	BH-21 (142m)	1.2	21.5	18.3	60.2	6900	0.3
Yayu	BH3-1 (62.25m)	11.06	43.99	18.65	54.07	5099	1.52
	BH10-1(78.35m)	10.98	46.53	11.32	42.15	5930.8	1.45
Mush Valley	In valley outcrop	1.6	27.4	33.1	37.9	4390	1.2
Nejo	Aleltu outcrop	8.1	44.7	5.3	41.9	4990	0.9
Wuchale	Outcrop	12.32	29.71	22.64	48.72	5761	1.25
Chilga	BH-27 (65.35m)	6.6	31.8	16.6	45.2	4599.5	0.4
Gojeb - Chida	Outcrop (1.2m)	7.7	29	31	32.3	5480	0.3
	Outcrop (1m)	13	31	20	38.7	4800	0.6
Lalo-Sapo	Bokai Outcrop	13.4	32.4	20.9	33.1	4120	0.4
Tercha	Outcrop	10.99	38.40	5.39	45.22	7300	0.46

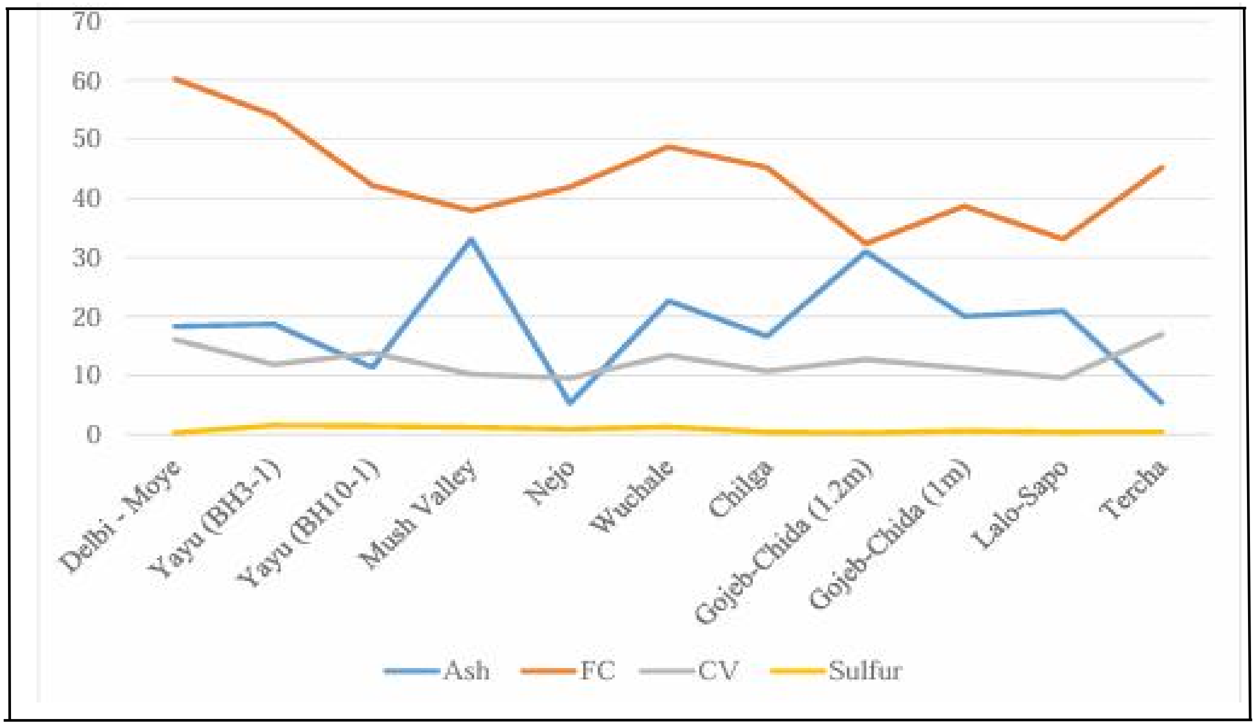


Figure 12: Ash content, fixed carbon (FC), calorific value (CV) and sulfur value comparison trend of Ethiopian coals. Ash, sulfur and FC values are in % and CV in MJ/Kg.(Wolela Ahmed, 2008).

CHAPTER THREE

3. REVIEW OF RELATED LITERATURE

3.1 Formation and usage of Coal

Coal is heterogeneous, consisting of carbonaceous matter (that is burned for energy) and volatile and mineral matter (that forms the impurities)(Anon 2015). Beneficiation, also known as cleaning, is essential for eliminating contaminants to ensure that coal complies with quality standards. The quality of the product is assessed using several parameters, including calorific value, ash content, sulfur levels, moisture, and the presence of fine particles. Additionally, two key parameters evaluate the efficiency of a specific beneficiation process: Equal Particle Misplacement (EPM) and the designated cut-point density. EPM acts as an indicator of how effectively coal can be differentiated from its impurities. The cut-point density refers to the density at which it is expected that 50% of the particles will be effectively separated.

It is essentially a combination of organic and inorganic materials that, over geological periods, transforms into a fuel characterized by a relatively high energy density through a process referred to as coalification. As coalification progresses, the energy density, or rank, of the coal rises, accounting for the considerable differences in coal quality observed worldwide. When possible, extracted coal is processed using physical beneficiation techniques to decrease the content of inorganic materials, which in turn improves energy density and lowers the presence of impurities in the fuel. This approach is mainly relevant for higher-ranking coals(Schweinfurth 2009).

Coal has been utilized by humans for an extensive period, leading to a comprehensive understanding of its properties. Its efficiency as a source of heat and the range of byproducts that can be produced from it are well acknowledged. However, a detailed examination of coal's intrinsic qualities, especially its mineral composition beyond sulfur and iron, has only been conducted in recent years(Deposited and Graphene 2019). Coal preparation, commonly known as washing, cleaning, processing, or beneficiation, involves the physical removal of unwanted impurities from coal to satisfy the specifications of various coal markets. This fossil fuel is primarily utilized for electricity generation, contributing to more than 39 percent of global

Energy production. Additionally, substantial quantities of coal are employed in metallurgical processes, cement production, gasification, and other applications. Furthermore, coal serves as a Precursor for activated carbon and a range of industrial chemicals (Reddy Ulavapalli et al. 2024). Beneficiation is essential for enhancing the quality of high-ash coals to fully realize their potential. At present, the wet beneficiation method is the most widely used technique for coal purification around the world (Dwari and Rao 2007).

3.2 Extraction techniques

Coal beneficiation has been utilized globally for over a hundred years and is generally categorized into two main types: wet beneficiation processes and dry beneficiation processes. Traditionally, wet beneficiation methods have been considered more effective than their dry counterparts.

Wet coal preparation involves the extraction of coal using a suspension, heavy liquid, or water, while dry coal preparation refers to methods conducted in an air environment. Both wet and dry coal preparation represent different strategies for coal cleaning, employing various techniques and procedures aimed at removing impurities from the coal(Xing, Gui, et al. 2017).

3.2.1 Dry Coal Preparation

Dry coal cleaning technologies include air-jigging (Gouri Charan et al. 2011), air-table(Anon 2019), FGX separator, and Reflux Classifier(Anon 2019). These methods offer effective solutions for the dry cleaning of coal. Nevertheless, when compared to wet cleaning techniques, the separation efficiency of these dry technologies tends to be relatively low in industrial applications.

Dry coal preparation, as the term suggests, refers to the method of cleansing coal of contaminants without utilizing water. This technique is particularly effective in conditions where coal is dry or water resources are limited. The advantages of dry coal preparation include reduced water consumption, lower operational expenses, and potential environmental benefits, as it eliminates the necessity for water treatment and disposal. Nevertheless, it may require a higher energy input for the separation processes when compared to wet coal preparation (Saga et al. 2015).

➢ **Critical Steps of the Dry Coal Preparation Process**

Crushing: Raw coal is fragmented into smaller particles. This crushing process facilitates the handling and transportation of coal, while also potentially enhancing the effectiveness of cleaning and beneficiation methods. By reducing the coal's size to a more manageable form and increasing its surface area, crushing can improve the efficiency of subsequent operations such as combustion, briquette production, and mineral extraction (Matusiak et al. 2021).

Screening: The crushed coal undergoes a sorting process to categorize it into different size classifications and remove larger impurities. Upon extraction from the earth, coal typically contains various contaminants, including rocks, debris, and other materials, necessitating the processes of crushing and screening. Screening machinery is employed to divide the coal into distinct sizes and grades, thereby ensuring that only premium-quality coal is processed and transported(Polat, Polat, and Chander 2003).

Air Dense Medium Fluidized Bed (ADMFB) Separation: Dry coal preparation often employs an ADMFB separator, a specialized device that uses air as the medium for separation instead of water. In this method, coal particles are suspended in an upward-moving stream of air, facilitating separation according to differences in density. The lighter coal particles ascend, while the heavier impurities settle at the bottom.(Fu et al. 2019).

Given that the ADMFB operates as a physical and gravity-driven process, a comprehensive understanding of the uniformity and stability of the fluidized bed density is crucial for its implementation. This knowledge is particularly significant for enhancing the efficiency and precision of dry coal separation (Firdaus et al. 2012). The viscosity of a fluidized bed is characterized by the mass of solid patches contained within a unit volume of the suspense, and it's significantly told by the hydrodynamic geste of the gas-solid fluidization system. generally, the ADMFB functions within the washing fluidization governance, which is marked by the presence of thrusting gas bubbles and the movement of patches propelled by the gas inflow.

Dry Densiometric Separation: Utilizes variations in density to distinguish coal from contaminants, employing air rather than water as the fluidizing agent. This technique, referred to

As dry gravity separation, is becoming increasingly favored as a substitute for conventional wet methods, owing to its potential for enhanced efficiency and diminished environmental consequences (Oshitani et al. 2016). Dry densiometric separation is a method utilized in the production of dry coal, relying on differences in the densities of coal and its impurities. This technique involves the application of an air stream that varies in both velocity and direction to the coal and impurities. As a result, contaminants and denser particles are effectively separated from the lighter coal particles.

3.2.2 Wet Coal Extraction

The method of wet coal extraction, commonly known as coal washing, employs water along with various mechanical and chemical techniques to eliminate impurities from coal. This technique, which utilizes water, resuspension liquids, or alternative liquids as the medium for separation, is termed wet coal extraction. Although it is widely adopted, this method is characterized by its significant water consumption(Liao et al. 2021). The product must undergo drying, dehydration (or de-medium), and a series of treatment processes involving muddy water from coal tailings (washing gangue). This procedure is quite complex and necessitates considerable financial investment and production costs.

- **Critical Steps of the Wet Coal Preparation Process**

Crushing: The unprocessed coal is broken down into finer particles to aid in the separation process(Matusiak et al. 2021).

Screening: The crushed coal is then screened or sifted through sieves to categorize it into various size fractions. This procedure assists in eliminating larger contaminants and enhancing the overall quality of the coal(Prakash, Majumder, and Singh 2018).

Dense Medium Separation (DMS): A dense medium, typically consisting of a suspension of finely ground magnetite in water, is employed in the wet extraction of coal to differentiate coal from impurities based on density variations. Heavier contaminants descend to the bottom, whereas the lighter coal particles remain buoyant. This method is particularly effective for eliminating shale and rock impurities(Meyer and Craig 2014).

Froth Flotation: Froth flotation is applicable in the wet preparation of coal, facilitating the separation of coal from impurities that possess comparable densities. In this process, coal is combined with water and a flotation agent, followed by the introduction of air bubbles (Usman et al. 2022b). Coal particles adhere to the bubbles and ascend to the surface, whereas the impurities stay suspended in the water. The froth that contains the coal is subsequently gathered and dried.

Dewatering: Following the separation process, coal typically undergoes dewatering methods to eliminate surplus water. This can be achieved through the use of centrifuges, filters, or various other dewatering machinery(Usman et al. 2022b).

A comprehensive examination of the solvent extraction process is essential for producing a suitable variety of coal, despite the widespread application of the wet extraction method in Ethiopia. Various elements, such as extraction time, the ratio of coal to solvent, filter dimensions, and the size of feed particles, considerably influence the wet coal extraction process. This study aims to understand and optimize these factors to enhance the yield of clean coal with minimal ash content.

3.3. Gap Analysis

Given that coal remains a primary fuel source in many regions globally, there is ongoing interest in optimizing coal utilization and advancing clean coal technologies[21, 22]. A comprehensive grasp of the essential characteristics of coal is necessary, highlighting the critical significance of coal characterization.

Coal undergoes chemical enhancement through two main methods to produce clean coal. The first method is Ultra Clean Coal (UCC), which focuses on improving coal quality by hydrothermally dissolving the minerals remaining in the organic coal structure with the use of potent acids or alkalis[21, 23], In the alternative approach, is ash-free coal, also known as hyper-coal, is reconstituted by employing organic solvents to extract the organic components [23, 28]. This category of coal is referred to as ash-free coal (AFC).

Nevertheless, the coal produced through the UCC process is unsuitable for direct combustion in gas turbines and may contain around 0.5% ash.[19, 20]. Another concern may arise from the biodegradability and corrosive nature of the strong acids and alkali reagents employed, as well as

The methods used for disposing of the waste solution. Nevertheless, it is possible to produce ash-free coal (AFC) with significantly lower ash content compared to that generated by the UCC process through the solvent extraction of coal using organic solvents. The residual coal, characterized by its high ash content, can be effectively utilized to generate steam or electricity in fluidized bed combustors due to its elevated heat value and minimal moisture content. Furthermore, the highly reactive leftover coals can serve as reducing agents in the extraction of synthetic rutile from ilmenite resources (Iino et al. 1988). Consequently, continuous research efforts are underway to identify both coal and solvents, particularly cost-effective industrial solvents, aimed at enhancing extraction yields and minimizing the residual coal left post-extraction.

Coal has been extracted for the production of AFC utilizing a range of solvents, which encompass polar, non-polar, and solvent mixtures (Shui, Wang, and Wang 2006). The attraction of the organic constituents within the coal matrix to an organic solvent is considered a key factor in the high-temperature solvent extraction process of coal. Conversely, in the process of coal flotation, collectors and frothers serve unique but interrelated functions that contribute to effective separation. Collectors increase the hydrophobic nature of coal particles, thereby facilitating their adhesion to air bubbles, while frothers provide stability to the generated froth, which is essential for successful collection and separation. The interplay between these reagents is thought to have a considerable influence on the structure and stability of the froth, as well as on the overall performance of the flotation process (Hadler, Aktas, and Cilliers 2005). This project employed a collector and frother in various mixture proportions, along with different coal sizes, to investigate the yield and ash content.

CHAPTER FOUR

4. MATERIALS AND METHODOLOGY

4.1 Materials and Reagents Used

Raw material with a quantity of 5kg collected from the Project site (Tercha Zuriya), as well as the materials used throughout the project work, were listed in Figure 13 (a-d) below.

Figure 13 : The lab equipment used in this project **(a)** Centrifugal Grinder (RETCH 56402 Deutschland) for laboratory purposes; **(b)** Jaw Crusher for laboratory use (RoHs53743)
(c) Various mesh-sized sieves & Sieve Vibrator (RETCH A200, Deutschland)
(d) Flotation Unit (Wedag Groppel 98, West Deutschland)

One sample(5kgs) obtained from the Tercha Zuriya Woreda were thoroughly ground using the grinder depicted in Figures 5(a) and (b). Subsequently, the ground samples were sieved to obtain various particle sizes, utilizing the apparatus illustrated in Figure 13 (c). Ultimately, the sieved samples of differing sizes($< 75\,\mu m - 500\mu m$) underwent a flotation process as represented in Figure 13 (d).

4.2 Sampling & Laboratory experiment

The samples brought from Tercha Zurita Woreda and crushed using a grinder were allowed to pass through the sieve having different mesh sizes range ($< 75\,\mu m - 500\mu m$). The sieve has three layers with $500\mu m$ at the top, $250\mu m$ in between, and $75\mu m$ at the bottom as shown in Figure 13 (c). Finally, the samples that remained on each plate of the sieve were collected in a plastic bag Figure 14(c), and (d) for further processes.

Figure 14 : Comminution (Size Reduction) Process in the Laboratory, showing **(a)** Raw Coal (**b**) Crushed Coal **(c)** Quartering of Coal **(d)** Grounded Coal

For each experiment, Tarcha coal sample was taken as a feed and mixed with tap water and stirred using high and low impeller speeds, until the coal particles were completely wetted & closing the air valve with scotch plaster enhanced wetting process.

4.2.1 The Proportion of Collector and Frother

In a flotation system, collectors serve as surfactant agents that alter the coal surface from hydrophilic to hydrophobic. Conversely, frothers must be present in adequate quantities to facilitate the flotation process, enabling them to adhere to the coal as the bubbles containing the components rise from the pulp (Mondal et al. 2021a).

S. Mondal, et al., 2021 assert that froth flotation is the most adaptable technique for the physical separation of particles, utilizing the differing affinities of air bubbles for various mineral surfaces within mineral or coal slurries(Mondal et al. 2021b). In this process, particles that remain fully

Saturated stay submerged in the liquid, while those that adhere to air bubbles rise to the surface and are subsequently removed.

In this research, flotation was conducted by utilizing the Collector-to-Frother ratio as a key parameter, which was categorized into three distinct ratios. The Collector-to-Frother proportions were set at 8:2, 8:4, and 8:6, respectively.

4.2.2 Froth Flotation Processes

Kerosene served as the collector, while 40 ppm or 0.12 ml of N-octanol was utilized as the frother. These specific collector and frothers were chosen due to their effective flotation capabilities and low cost (Shean and Cilliers 2011). The selection of the ratio between the collector and frother was determined based on the specified proportions and samples categorized by their respective sizes. During the procedure, each sample was introduced into the flotation unit and agitated for three minutes. Subsequently, an air valve was activated to introduce air into the flotation cell, facilitating the formation of bubble particles. Once bubble formation commenced, one liter of water was added to each sample to ensure the flotation cell's capacity was met. The process of bubble particle formation persisted until the foam overflowed from the cell, at which point the excess foam was successfully collected. This ongoing cycle of foam generation and collection continued until the appearance of white foam was noted, signifying that all solid particles within the cell had adhered to the kerosene oil collectors. Finally, the collected particles were dried in a hot oven at 80°C for three hours, and the yield was calculated using the equation provided below for each experimental run conducted (Journal et al. 2020).

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

To assess the ash content in coal, the ASTM D3174 method was employed, which involves combusting a sample under regulated conditions. The residual material, known as ash, was subsequently weighed and reported as a percentage of the initial weight of the sample. The coal sample was contained in a crucible and subjected to combustion in a muffle furnace at a designated temperature of 750°C for eight hours. The ash percentage for each sample obtained during this procedure was then calculated using the formula provided below.

$$Ash\ (\%) = \frac{Wt. of\ Redidual\ left\ after\ burning\ (g)}{Wt. of\ Feed\ Coal\ (g)} x100 \ldots\ldots \qquad [3.2]$$

CHAPTER FIVE

5. RESULT AND DISCUSSION

The experiments focused on the yield percentage and ash content to evaluate the effectiveness of flotation. Ash content indicates the amount of undesirable material remaining, while yield percentage reflects the proportion of valuable material successfully separated. To analyze its impact on the results, the studies varied the ratio of collector to frother; for instance, increasing the amount of collector could enhance the extraction of essential minerals (Batjargal et al. 2023). Additionally, various particle sizes were examined, as larger or smaller particles may exhibit different flotation behaviors. To ensure reliable results, certain parameters were kept constant throughout the testing process. The volume of raw samples introduced into the system remained unchanged, as did the speed of the rotating mixer. This approach ensured that any variations in the results could be attributed solely to the differences in particle size and the ratio of the collector to frother.

Consequently, the study primarily focused on particle size and the effects of the collector-to-frother ratio. These factors can influence both the ash content and the yield. We investigated how different particle sizes affected the flotation process and assessed the relative amounts of collector and frother. Our interest lies in understanding how these quantities influence the outcomes. The yield percentage reflects the amount of valuable material recovered, while the ash content indicates the presence of unwanted minerals in the final product. The results of these experiments are presented below.

5.1 Effects of Particle Size and Collector to Frother on Yield

The yield percentage, influenced by variations in particle size and the ratio of frother to collector, was analyzed in the flotation process, with the findings presented in Table 3.

Table 3: The effect of Particle Size and Collector-to-Frother on Yield Percentage

Particle Size	Collector-Frother Combination		
	(8:2)	(8:4)	(8:6)
-500+250	77.4	81.1	80.2
-250+150	81.2	84.9	84.5
-75	81.7	82.9	82.8

Both particle size and the ratio of the collector to frother in the froth flotation process. At a collector-to-frother ratio of 8:2, the yield percentages for the -500+250, -250+150, and -75 sieve sizes were recorded at 77.4%, 81.2%, and 81.7%, respectively. When the frother concentration was increased to a ratio of 8:4, there was a notable enhancement in yields across all size fractions, with percentages rising to 81.1%, 84.9%, and 82.9% for the respective sieve sizes. A further increase in frother concentration to an 8:6 ratio produced yields of 80.2%, 84.5%, and 82.8% for the -500+250, -250+150, and -75 particle sizes, suggesting the presence of an optimal frother concentration within the examined range.

5.1.1 Effect of Particle Size on Yield Percentage

To investigate the effect of particle size on the yield percentage is shown in figure 15 below.

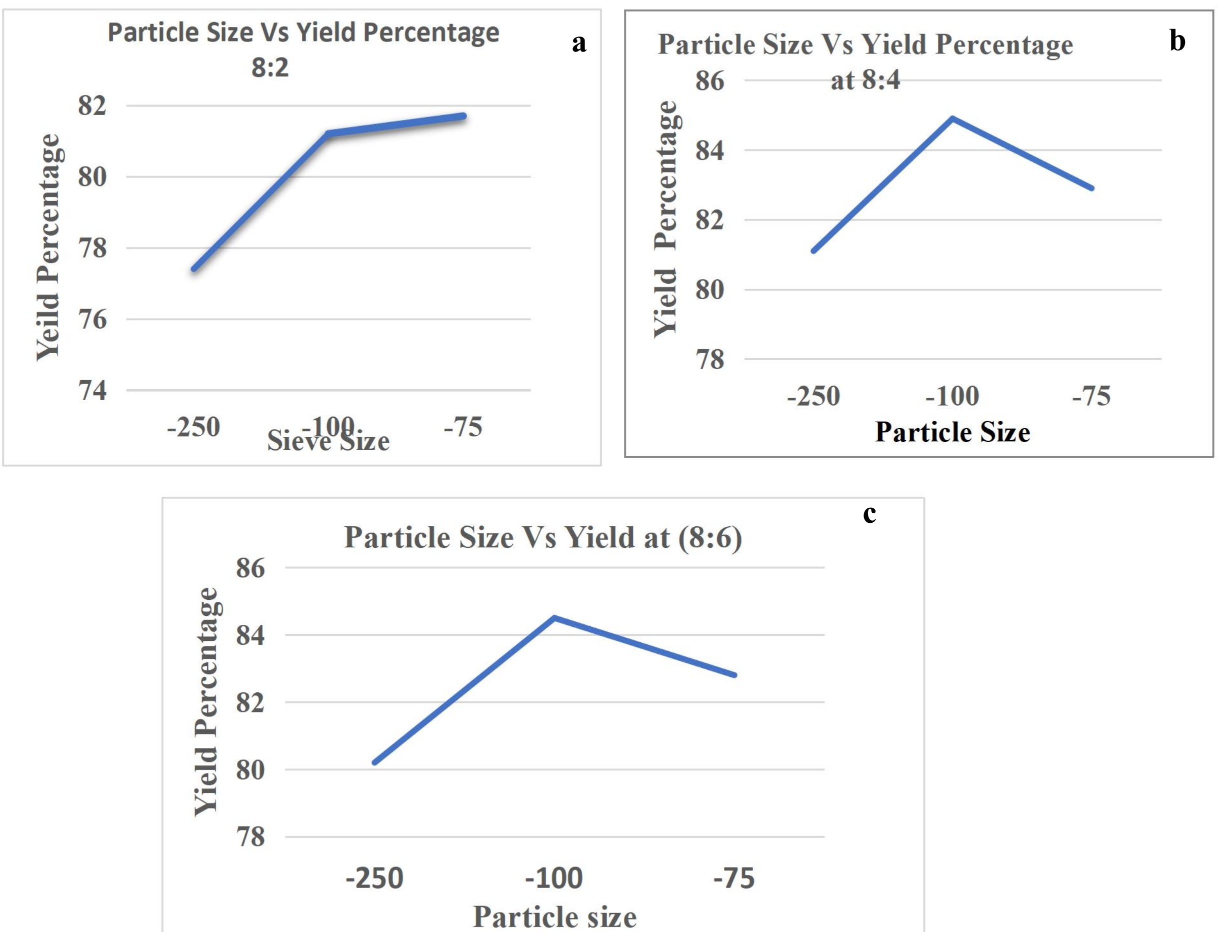


Figure 15 : The Effects of Particle Size on the Yield Percentage with Collector-to-Frother ratio becomes (a) 8:2, (b) 8:4, and (c) 8:6

The data illustrated in the diagram indicates a stable trend in yield percentage across the three experimental conditions (Collector to Frother ratios of 8:2, 8:4, and 8:6). It is particularly noteworthy that the highest yield is consistently achieved when the input particle size is at -100. Additionally, a distinct pattern is observed where the yield percentage increases in direct relation to particle size, peaking at the -100 level. However, once the particle size exceeds -100, there is a significant decline in yield percentage, implying a diminishing return or adverse impact on the process as particle size becomes excessively large. This finding underscores the necessity of regulating particle size within a defined range to optimize yield, with -100 identified as the most favorable target.

5.1.2 Effects of Collector to Frother on Yield Percentage

The yield percentage of coal processed with Collector and Frother is presented in Table 3 above, with further details illustrated in Figure 16 below.

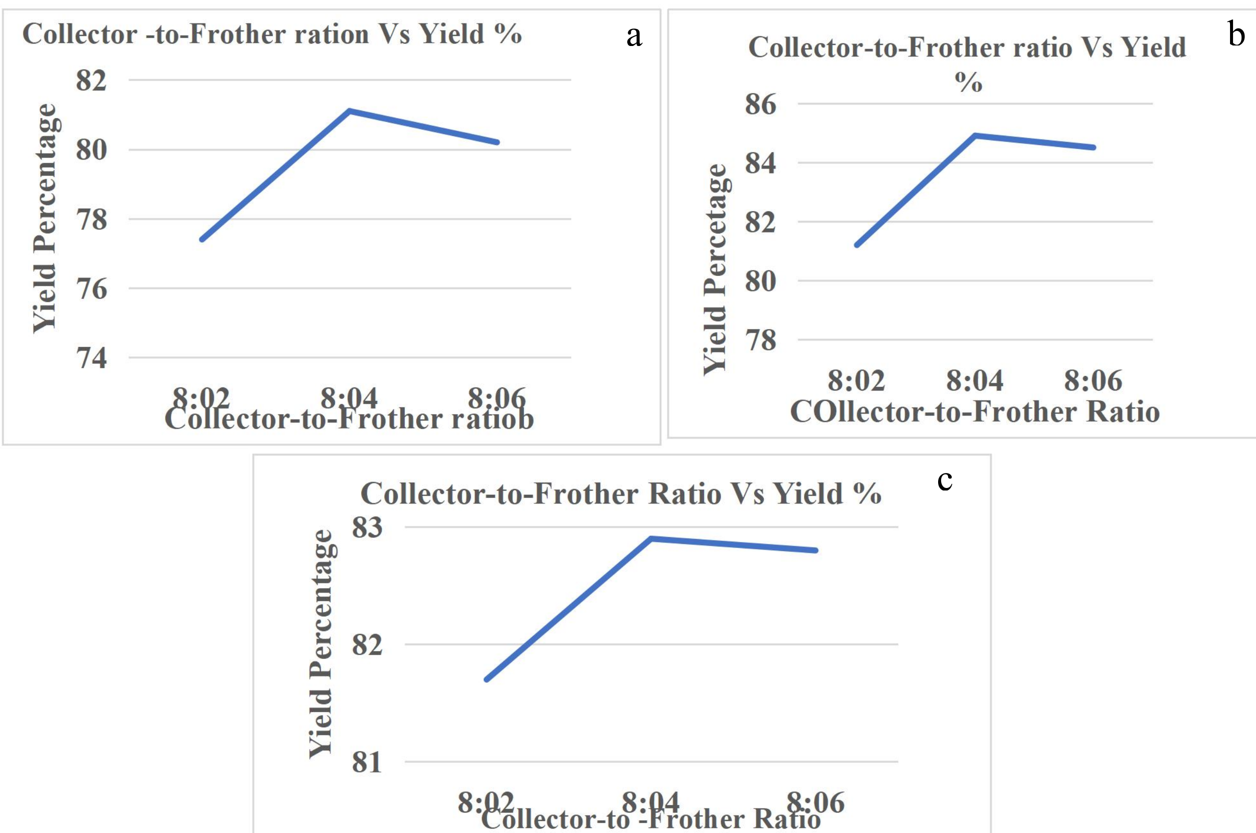


Figure 16 : The Effects of Collector to Frother Ration on the Yield Percentage with Particle sizes (a) -250, (b) -100, and (c) -75

In the three experimental conditions involving particle sizes of -250, -100, and -75, the data presented in Figure 8 indicates a consistent trend in yield percentage. It is particularly noteworthy that a Collector-to-Frother ratio of 8:4 frequently produces the highest yield. Additionally, there is a discernible pattern demonstrating that the yield percentage increases in direct correlation with the Collector-to-Frother ratio, peaking at 8.4. However, when the Collector-to-Frother ratio exceeds an optimal level, there is a marked decline in yield percentage, suggesting diminishing returns or adverse effects on the process. This finding underscores the importance of maintaining the Collector-to-Frother ratio within a defined range, with 8:4 identified as the most effective target for maximizing yield.

5.2 Effects of Particle Size and Collector to Frother on Ash Content

The relationship between the collector and Frother, along with other factors such as airflow rate and collector dosage, can greatly influence the percentage of coal yield in the froth flotation process (AKSOY* and Department 2016). Collectors and depressants are two essential types of surfactants that predominantly adsorb at the solid-liquid interface. Collectors increase the hydrophobic properties of mineral particles, facilitating their flotation, whereas depressants diminish the hydrophobicity of gangue particles, thereby inhibiting their flotation. On the other hand, frothers primarily adsorb at the gas-liquid interface. They play a critical role in regulating bubble size, ascent velocity, and the stability and movement of the froth phase. As the concentration of frother increases, the dimensions of air bubbles within a flotation cell diminish. This increase in frother concentration inhibits the merging of colliding air bubbles by reinforcing the thin liquid film that develops between them and lowering the interfacial (gas-liquid) tension. The impact of ash content, influenced by the varying sizes of raw materials and the collector-frother, is is presented in Table 2 below.

Table 4: The Effect of Particle Size and Collector-to-Frother on the Ash Content.

Particle size Range (μm)	Collector-to-Froather ratio		
	8:2	8:4	8:6
-500+250	7.2	7.4	7.5
-250+150	7.6	7.2	7.6
-75	8.3	8.2	8.64

The table above (Table 4) demonstrates that the ash concentration in floating coal increases as the particle size decreases, aligning with the findings presented on the above table (Table 4). The ash content in coal is influenced by the ratio of Collector to Frother, as shown in Table 4. The results reveal that the ash content diminishes when the collector ratio is adjusted from 8:2 to 8:4, but subsequently rises again when the ratio is modified to 8:6. Furthermore, the distinct effects of particle size and collector-to-frother ratio on the ash content of coal are illustrated separately in Figures 17 and 18.

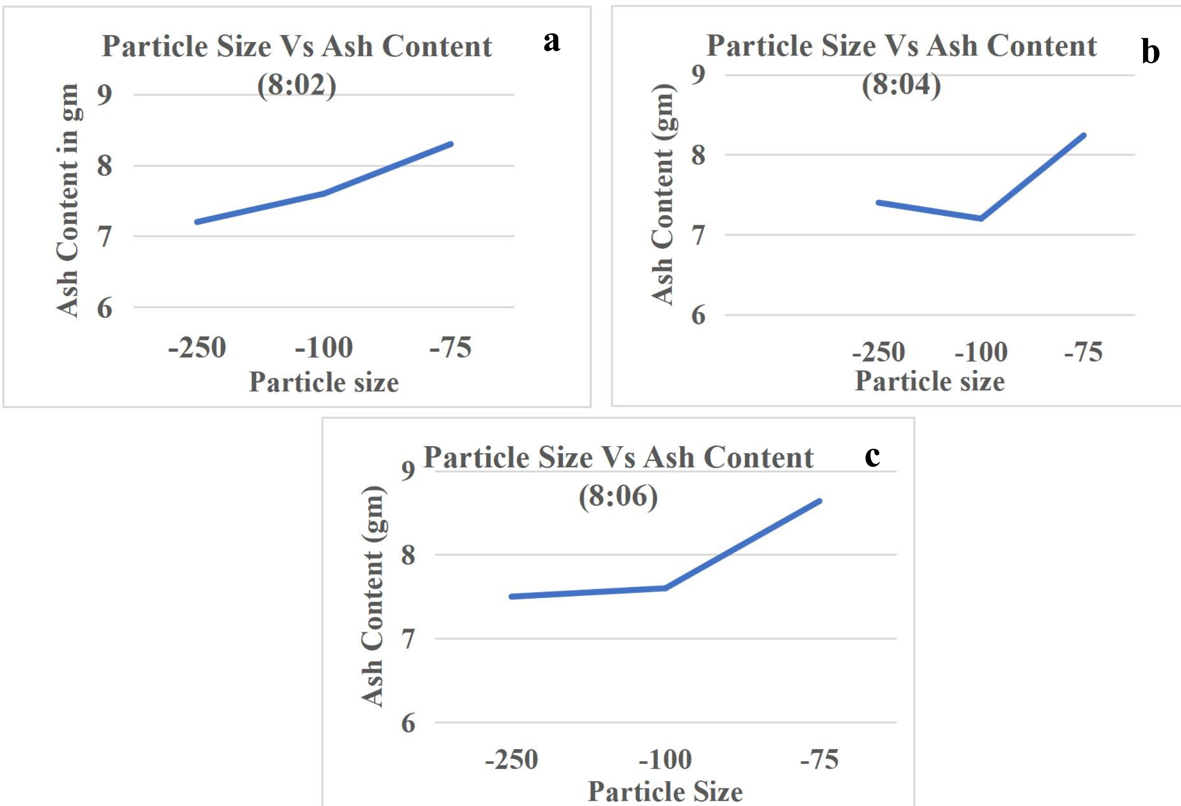


Figure 17 : The Effects of Particle Size on the Ash with Collector-to-Frother ratio becomes (a) 8:2, (b) 8:4, and (c) 8:6

It is well established that coal with finer particle sizes generally produces greater amounts of ash. Conversely, coal with coarser particle sizes usually exhibits a higher fixed carbon content and a lower initial ash content, which may subsequently rise. This occurrence is associated with the development of ash particles and the combustion properties of the coal. As demonstrated in Figures 17 (a) to (c), there is a correlation between decreasing particle size and increasing ash content, consistent with anticipated trends (Lanzerstorfer 2018).

On the other hand, the effect of Collector-to-Frother on ash content was examined and the result is shown in Figure 18 below.

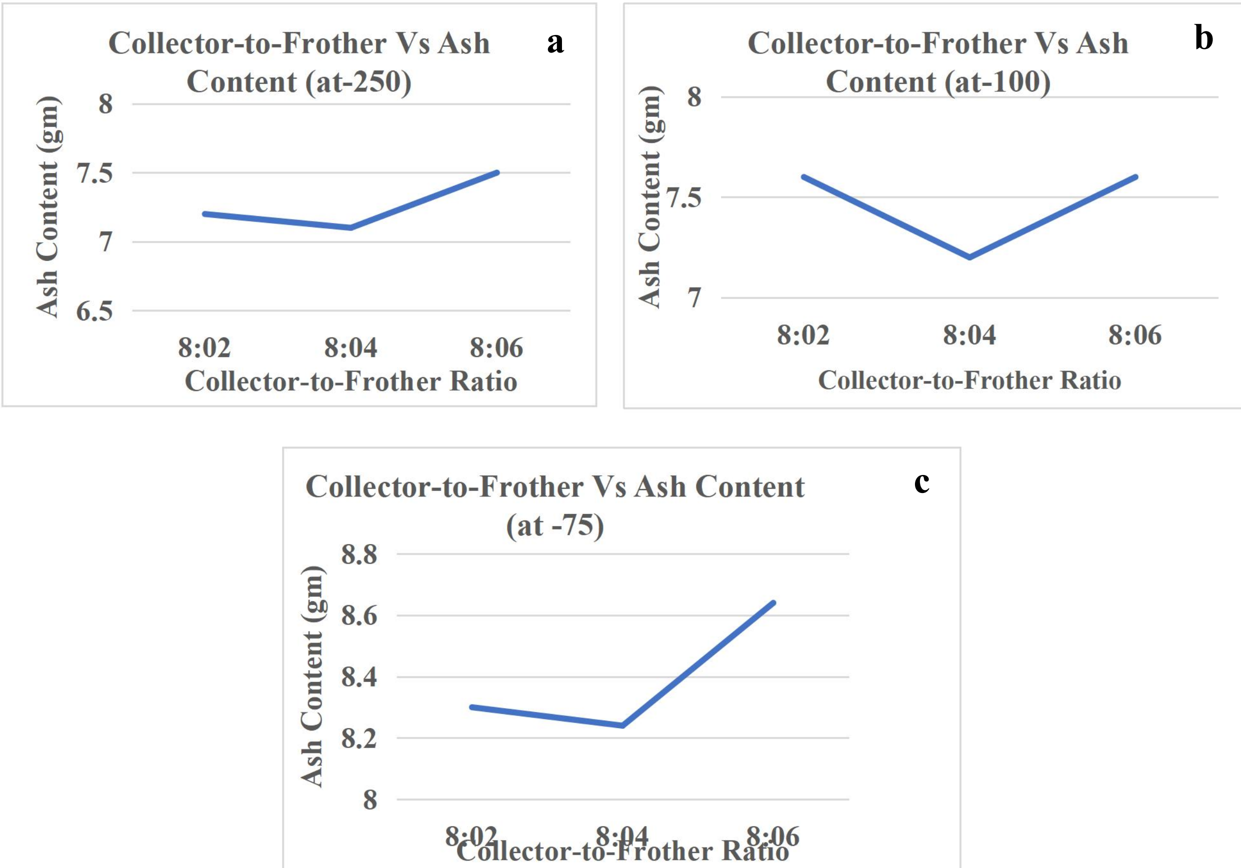


Figure 18 : The Effects of Collector-to-Frother Ration on the Ash Content with particle size (a) -250, (b) -100, and (c) -75

The illustration presented in Figure 18 illustrates how the ratio of the collector to frother influences the ash content in the resulting coal while maintaining consistent particle sizes. In Figure18 (a), the ratio ranges from 8:2 to 8:6, with a particle size of -250. Figure 18 (b) features a particle size of -100, whereas Figure 18(c) displays a size of -75, each associated with varying collector-to-frother ratios. The results from these three experiments indicate that the ash content reaches its lowest level at an 8:4 collector-to-frother ratio.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Several essential parameters required meticulous regulation to investigate coal flotation. To ensure a stable process, adjustments were made to the raw coal particle size and the ratio of collector to frother, while keeping the feed quantity, impeller speed, and other relevant factors constant. This methodology facilitated a focused assessment of both the individual and combined effects of these variables on the separation process. It was determined that particle size and the collector-to-frother ratio significantly influenced flotation performance, particularly regarding ash content and the yield of clean coal. Therefore, optimizing these parameters is vital for enhancing the efficiency and quality of coal beneficiation.

The results suggest that although particle size affects the yield percentage, it is not the only factor at play. When the input particle size is larger, the yield percentage tends to be low; however, it increases as the particle size diminishes, especially for the collector-to-frother ratios of 8:2 and 8:6. Conversely, for the 8:4 ratio, the yield is maximized at a particle size of -100, which falls within the intermediate range. As the literature (Zhang et al. 2017) indicates, the efficiency of flotation is affected by the interactions that occur during the collision, attachment, and detachment of particles and bubbles. Furthermore, the dimensions of coal particles significantly impact the flotation characteristics of mineral particles, which is consistent with the findings observed.

The ash content of the final product was analyzed, indicating that it is affected by both particle size and the ratio of collector to frother. In particular, a drop in flyspeck size correlates with an increase in ash content. This phenomenon can be attributed to the fact that smaller particles often contain a greater concentration of impurities, resulting in higher ash levels. In contrast, the analysis revealed that the minimum ash content occurred at a collector-to-frother ratio of 8:4.

The experiment ultimately demonstrated that the optimal results were achieved with a collector-to-frother ratio of 8:4 and a particle size of -100. Under these conditions, the yield percentage peaked at 84.9, while the ash content was reduced to 7.2.

6.2 Recommendation

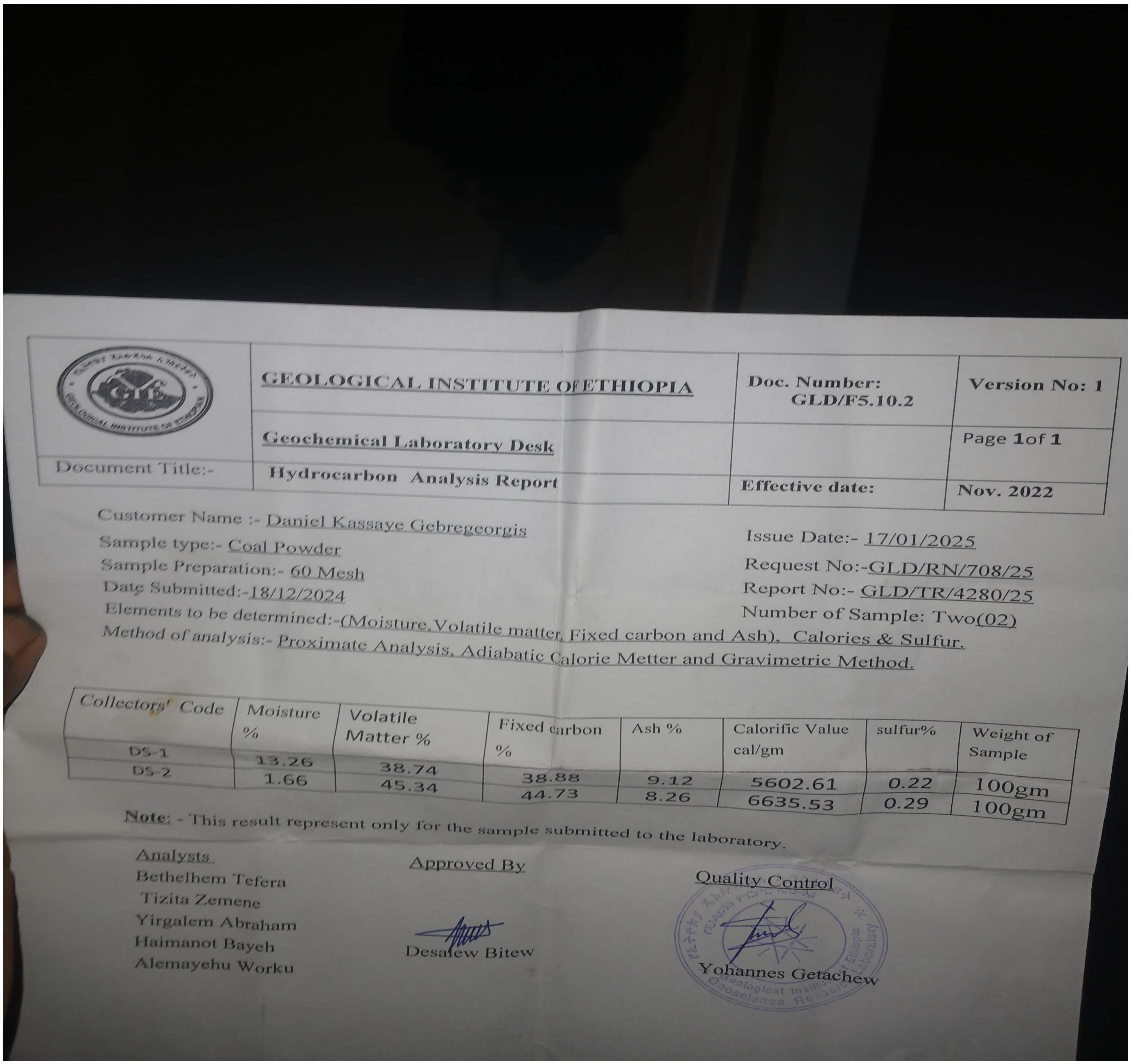
The research results underscored the advancements made in the coal mine situated in Tercha Zuriya Wereda. Based on these findings, the researcher put forward a series of recommendations designed to enhance flotation efficiency and reduce ash content.

- Considering other variables like rotation speed, considering time and pH of the floatation
- Considering other collectors and frothers
- Monitor the impurity before experimenting with floatation.
- Conducting enhancing coal using different methods (Other wet method and dry methods)

The findings indicate a clear understanding of how particle size and the ratio of the collector to frother influence both yield and ash content. Implementing these recommendations effectively has the potential to promote more sustainable coal mining practices while also offering considerable economic benefits to coal companies.

Appendix

Proximate analysis results for Tarcha coal



	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Hydrocarbon Analysis Report	Effective date:	Nov. 2022

Customer Name :- Daniel Kassaye Gebregeorgis

Sample type:- Coal Powder

Sample Preparation:- 60 Mesh

Date Submitted:-18/12/2024

Issue Date:- 17/01/2025

Request No:-GLD/RN/708/25

Report No:- GLD/TR/4280/25

Number of Sample: Two(02)

Elements to be determined:-(Moisture,Volatile matter, Fixed carbon and Ash), Calories & Sulfur.

Method of analysis:- Proximate Analysis, Adiabatic Calorie Metter and Gravimetric Method.

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value cal/gm	sulfur%	Weight of Sample
DS-1	13.26	38.74	38.88	9.12	5602.61	0.22	100gm
DS-2	1.66	45.34	44.73	8.26	6635.53	0.29	100gm

Note: - This result represent only for the sample submitted to the laboratory.

Analysts
Bethelhem Tefera
Tizita Zemene
Yirgalem Abraham
Haimanot Bayeh
Alemayehu Worku

Approved By
Desalew Bitew

Quality Control
Yohannes Getachew

REFERENCES

Abebay, Getaneh, Endalu Tadele Chala, Nagessa Zerihun Jilo, and Tiyasha Tiyasha. 2024a. “Improving the Stability of Mining Slopes in Tarcha Coal Mine , Southwestern Ethiopian Deposit Through Geometric Adjustments.” *Advances in Civil Engineering* 2024. doi: 10.1155/2024/8925294.

Abebay, Getaneh, Endalu Tadele Chala, Nagessa Zerihun Jilo, and Tiyasha Tiyasha. 2024b. “Improving the Stability of Mining Slopes in Tarcha Coal Mine , Southwestern Ethiopian Deposit Through Geometric Adjustments.” 2024. doi: 10.1155/2024/8925294.

Ahmed, Wolela. 2016. “FOSSIL FUEL ENERGY RESOURCES OF ETHIOPIA Wolela.” *Bull. Chem. Soc. Ethiop. 2008, 22(1), 67-84* 22(1):1–23.

AKSOY*, Derya ÖZ, and Department. 2016. “The Effect of Collector, Frother Dosage and Their Interaction on The Flotation of Bottom Ash by Full Factorial Design.” *Anadolu University Journal of Science and Technology A- Applied Sciences and Engineering 2016* 17(3):594–604. doi: 10.18038/btda.45571.

Anon. 2015. “SACPS (South African Coal Processing Society). 2015. Coal Preparation in South Africa. Natal Witness Commercial Printers, Pietermaritzburg.”

Anon. 2019. “Dry Coal Beneficiatio Technique in the Gas-Solid Fluidized Bed: A Review.” *International Journal of Coal Preparation and Utilization*. doi: 10.1080/19392699.2019.1678469.

Batjargal, Khandjamts, Onur Guven, Orhan Ozdemir, Stoyan I. Karakashev, Nikolay A. Grozev, Feridun Boylu, and Mehmet Sabri Çelik. 2023. “Frothing Performance of Frother-Collector Mixtures as Determined by Dynamic Foam Analyzer and Its Implications in Flotation.” *Minerals* 13(242):1–17.

Bian, Liang, Hai long Li, Yu jin Li, Jia nan Nie, Fa qin Dong, Hai liang Dong, Mian xin Song, Li sheng Wang, Tian liang Zhou, Xiao yan Zhang, Xin xi Li, and Lei Xie. 2017. “Enhanced Photovoltage Response of Hematite-X-Ferrite Interfaces (X = Cr, Mn, Co, or Ni).” *Nanoscale Research Letters* 12(1):2–7. doi: 10.1186/s11671-017-1885-3.

Chandran Govindaraju, V. G. R., and Chor Foon Tang. 2013. “The Dynamic Links between CO2 Emissions, Economic Growth and Coal Consumption in China and India.” *Applied Energy* 104:310–18. doi: 10.1016/j.apenergy.2012.10.042.

Dash, P. S., R. K. Lingam, S. Santosh Kumar, A. Suresh, P. K. Banerjee, and S. Ganguly. 2015. “Effect of Elevated Temperature and Pressure on the Leaching Characteristics of Indian Coals.” *Fuel* 140:302–8. doi: 10.1016/j.fuel.2014.09.110.

Demirbas, M. F. 2007. "Progress of Fossil Fuel Science." *Energy Sources, Part B: Economics, Planning and Policy* 2(3):243–57. doi: 10.1080/15567240500402909.

Deposited, Chemical Vapour, and Epitaxial Graphene. 2019. "Graphene-Based Ammonia Sensors Functionalised." *Sensors* 1–17. doi: 10.3390/s19040951.

Dwari, R. K., and K. Hanumantha Rao. 2007. "Dry Beneficiation of Coal - A Review." *Mineral Processing and Extractive Metallurgy Review* 28(3):177–234. doi: 10.1080/08827500601141271.

Firdaus, Muhamad, John-paul O. Shea, Jun Oshitani, and V. George. 2012. "Beneficiation of Coarse Coal Ore in an Air-Fluidized Bed Dry Dense-Medium Separator." *International Journal of Coal Preparation and Utilization* 32(6):276–89. doi: 10.1080/19392699.2012.716801.

Fu, Zhijie, Jesse Zhu, Shahzad Barghi, Yuemin Zhao, Zhenfu Luo, and Chenlong Duan. 2019. "The Distribution of Bed Density in an Air Dense Medium Fl Uidized Bed with Single and Binary Mixtures of Geldart B and / or D Particles." *Minerals Engineering* 142:1–9. doi: 10.1016/j.mineng.2019.105926.

Girma, Firehiywet, and Betelihem Teshome. 2023. "Multicriteria Spatial Model to Select Landfill Sites for Solid Waste Management in Tercha Town, Southwest Ethiopia." *Cogent Social Sciences* 9(2). doi: 10.1080/23311886.2023.2264626.

Gouri Charan, T., U. S. Chattopadhyay, K. M. P. Singh, S. K. Kabiraj, and D. D. Haldar. 2011. "Beneficiaron of High-Ash, Indian Non-Coking Coal by Dry Jigging." *Minerals and Metallurgical Processing* 28(1):21–23. doi: 10.1007/bf03402320.

Hadler, K., Z. Aktas, and J. J. Cilliers. 2005. "The Effects of Frother and Collector Distribution on Flotation Performance." *Materials Engineering* 18:171–77. doi: 10.1016/j.mineng.2004.09.014.

Hodouin, D., C. Bazin, E. Gagnon, and F. Flament. 2000. "Feedforward – Feedback Predictive Control of a Simulated Flotation Bank." 2–8.

Iino, Masashi, Toshimasa Takanohashi, Hironori Ohsuga, and Kiminori Toda. 1988. "Extraction of Coals with CS2-N-Methyl-2-Pyrrolidinone Mixed Solvent at Room Temperature. Effect of Coal Rank and Synergism of the Mixed Solvent." *Fuel* 67(12):1639–47. doi: 10.1016/0016-2361(88)90208-6.

Journal, An International, Ajita Kumari, Alok Tripathy, and Venugopal Rayasam. 2020. "Performance Characterization and Misplacement Studies of Liquid – Solid Fluidized Bed Density Separator for Coal Beneficiation Using Taguchi- ANOVA Method." *Particulate Science and Technology* 0(0):1–

13. doi: 10.1080/02726351.2020.1751357.

Lanzerstorfer, Christof. 2018. "Fly Ash from Coal Combustion : Dependence of the Concentration of Various Elements on the Particle Size." *Fuel* 228(May 2017):263–71. doi: 10.1016/j.fuel.2018.04.136.

Liao, Xiaoxue, Bo Wang, Liang Wang, Jintuo Zhu, Peng Chu, Zibin Zhu, and Siwen Zheng. 2021. "Experimental Study on the Wettability of Coal with Di Ff Erent Metamorphism Treated by Surfactants for Coal Dust Control." doi: 10.1021/acsomega.1c02205.

Lin, Dan, Li Liu, Yan Zhao, Yijun Zhao, Penghua Qiu, Xing Xie, and Shaozeng Sun. 2020. "In Fluence of Pyrolysis Pressure on Structure and Combustion Reactivity of Zhundong Demineralized Coal Char." *Journal of the Energy Institute* 93(5):1798–1808. doi: 10.1016/j.joei.2020.03.011.

Matusiak, Piotr, Daniel Kowol, Tomasz Suponik, Dawid M. Franke, Paweł M. Nuckowski, and Barbara Tora. 2021. "Selective Crushing of Run-of-Mine as an Important Part of the Hard Coal Beneficiation Process." *Energies* 14(3167):1–16.

Meyer, E. J., and I. K. Craig. 2014. "Coal Dense Medium Separation Dynamic and Steady-State Modelling for Process Control." *MINERALS ENGINEERING* 65:98–108. doi: 10.1016/j.mineng.2014.05.018.

Mondal, Sangita, Animesh Acharjee, Ujjwal Mandal, and Bidyut Saha. 2021a. "Froth Flotation Process and Its Application." *Vietnam J. Chem* 59(4):417–25. doi: 10.1002/vjch.202100010.

Mondal, Sangita, Animesh Acharjee, Ujjwal Mandal, and Bidyut Saha. 2021b. "Froth Flotation Process and Its Application." *Vietnam J.Chem* 59(4):417–25. doi: 10.1002/vjch.202100010.

Oshitani, Jun, Kazuhiro Teramoto, Mikio Yoshida, Yasuo Kubo, Shingo Nakatsukasa, and George V Franks. 2016. "Dry Beneficiation of Fine Coal Using Density-Segregation in a Gas – Solid Fluidized Bed." *Advanced Powder Technology* 1–5. doi: 10.1016/j.apt.2016.05.032.

Polat, M., H. Polat, and S. Chander. 2003. "Physical and Chemical Interactions in Coal Flotation." *International Journal of Mineral Processing* 72:199–213. doi: 10.1016/S0301-7516(03)00099-1.

Prakash, Ritesh, Subrata Kumar Majumder, and Anugrah Singh. 2018. "Flotation Technique: Its Mechanisms and Design Parameters Authors:" *Chemical Engineering & Processing: Process Intensification*. doi: 10.1016/j.cep.2018.03.029.

Reddy Ulavapalli, Gangadhara, Rambabu Koyilapu, T. Gouri Charan, V. Murali Krishna, and G. V.

Subba Reddy. 2024. "Coal Quality Enhancement by Using Bio Extracts of Carissa Carandas Fruits in Combination with Hydro Fluoric Acid." *International Journal of Coal Preparation and Utilization* 44(12):2119–38. doi: 10.1080/19392699.2024.2310653.

Remes, A. 2007. "Effect of Speed and Accuracy of On-Line Elemental Analysis on Flotation Control Performance." 20:1055–66. doi: 10.1016/j.mineng.2007.01.016.

Ristinen, Robert, and Jack Kraushaar. 2006. "Energy and the Environment, 2nd Edition."

Ryberg, Morten W., Mikołaj Owsianiak, Alexis Laurent, and Michael Z. Hauschild. 2015. "Power Generation from Chemically Cleaned Coals: Do Environmental Benefits of Firing Cleaner Coal Outweigh Environmental Burden of Cleaning?" *Energy and Environmental Science* 8(8):2435–47. doi: 10.1039/c5ee01799h.

Saga, Kiyotaka, Fumio Hasegawa, Syoko Miyagi, Sueko Atobe, Shigeru Okada, and Kenji Imou. 2015. "Comparative Evaluation of Wet and Dry Processes for Recovering Hydrocarbon from Botryococcus Braunii." *APPLIED ENERGY* 141:90–95. doi: 10.1016/j.apenergy.2014.12.018.

Schweinfurth, S. P. 2009. "An Introduction to Coal Quality." *The National Coal Resource Assessment Overview: Professional Paper 1625-F* (March):16.

Shan, Yuli, Petar S. Varbanov, and Kexi Pan. 2014. "Footprints Evaluation of China ' s Coal Supply Chains." *Proceedings of the 24th European Symposium on Computer Aided Process Engineering* – 2014:1880–84. doi: 10.1016/B978-0-444-63455-9.50148-3.

Shean, B. J., and J. J. Cilliers. 2011. "A Review of Froth Flotation Control." *International Journal of Mineral Processing* 100:57–71. doi: 10.1016/j.minpro.2011.05.002.

Shui, Hengfu, Zhicai Wang, and Gaoqiang Wang. 2006. "Effect of Hydrothermal Treatment on the Extraction of Coal in the CS2/NMP Mixed Solvent." *Fuel* 85(12–13):1798–1802. doi: 10.1016/j.fuel.2006.02.005.

Steel, Karen M., and John W. Patrick. 2001. "The Production of Ultra Clean Coal by Chemical Demineralisation." *Fuel* 80(14):2019–23. doi: 10.1016/S0016-2361(01)00092-8.

Takanohashi, Toshimasa, Takahiro Shishido, Hiroyuki Kawashima, and Ikuo Saito. 2008. "Characterisation of HyperCoals from Coals of Various Ranks." *Fuel* 87(4–5):592–98. doi: 10.1016/j.fuel.2007.02.017.

Upgupta, Sujata, and Prasoon Kumar Singh. 2018. "Impacts of Coal Mining : A Review of Methods and

Parameters Used in India Impacts of Coal Mining : A Review of Methods and Parameters Used in India." *Current World Environment* 12(1):142–56. doi: 10.12944/CWE.12.1.17.

Usman, Temam, Samuel Abicho, Daniel Meshesha, and Getachew Adam. 2022a. "Froth Flotation Beneficiation and Physiochemical Characterization of Coal from Achibo-Sombo-Dabaso Area, Southwestern Ethiopia." *Heliyon* 8(11):e11313. doi: 10.1016/j.heliyon.2022.e11313.

Usman, Temam, Samuel Abicho, Daniel Meshesha, and Getachew Adam. 2022b. "Froth Flotation Beneficiation and Physiochemical Characterization of Coal from Achibo-Sombo-Dabaso Area , Southwestern Ethiopia." *Heliyon* 8(October):e11313. doi: 10.1016/j.heliyon.2022.e11313.

Wang, Qikun, Qibing Chang, Yongqing Wang, Xia Wang, and Jian-er Zhou. 2016. "Ultra Fi Ne CoAl 2 O 4 Ceramic Pigment Prepared by Pechini-Sacri Fi Cial Agent Method." 173:64–67. doi: 10.1016/j.matlet.2016.03.014.

Wolela, Ahmed. 2007. "Fossil Fuel Energy Resources of Ethiopia: Coal Deposits." *International Journal of Coal Geology* 72(3–4):293–314. doi: 10.1016/j.coal.2007.02.006.

Xing, Yaowen, Xiahui Gui, Yijun Cao, Yingwei Wang, Mengdi Xu, Dongyue Wang, and Chenwei Li. 2017. "Effect of Compound Collector and Blending Frother on Froth Stability and Fl Otation Performance of Oxidized Coal." *Powder Technology* 305:166–73. doi: 10.1016/j.powtec.2016.10.003.

Xing, Yaowen, Xuehong Xu, Xiahui Gui, Yijun Cao, and Mengdi Xu. 2017. "Effect of Kaolinite and Montmorillonite on Fine Coal Flotation." *Fuel* 195:284–89. doi: 10.1016/j.fuel.2017.01.058.

Zhang, Ning-ning, Chang-chun Zhou, Cheng Liu, Jin-he Pan, Meng-cheng Tang, Shan-shan Cao, Chang-heng Ouyang, and Chang-bin Peng. 2017. "Effects of Particle Size on Flotation Parameters in the Separation of Diaspore and Kaolinite." *Powder Technology*. doi: 10.1016/j.powtec.2017.04.049.

Zhao, Yu, Shuxiao Wang, Lei Duan, Yu Lei, Pengfei Cao, and Jiming Hao. 2008. "Primary Air Pollutant Emissions of Coal-Fired Power Plants in China: Current Status and Future Prediction." *Atmospheric Environment* 42(36):8442–52. doi: 10.1016/j.atmosenv.2008.08.021.

Geleta Warkisa Deressa, Bhanwar Singh Choudhary, Nagessa Zerihun Jilo, Advanced bench design and technical challenges in open pit mining: a comprehensive review of stability and productivity, Arabian Journal of Geosciences, 10.1007/s12517-024-12157-2, 18, 1, (2025)

Tefera M., Chernet T., Haro W., Teshome N., Woldie K., and Sarvéy Y., Explanation of the Geological Map of Ethiopia Scale 1: 2000,000, 1996.

Woldegabriel G., Aronson J. L., and Walter R. C., Geology, Geochronology, and Rift Basin Development in the Central Sector of the Main Ethiopia Rift, Geological Society of America Bulletin. (1990) 102, no. 4, 439–458

Wolela A., Fossil Fuel Energy Resources of Ethiopia: Coal Deposits, International Journal of Coal Geology. (2007) 72, no. 3-4, 293–314, https://doi.org/10.1016/j.coal.2007.02.006, 2-s2.0-35548938569.

Davidson A., The Omo River Project: Reconnaissance Geology and Geochemistry of Parts of Ilubabor, Kefa, Gemu Gofa and Sidamo, Ethiopia, 1983, [publisher not identified] [Place of publication not identified], Addis Ababa.

Kazmin V., Geological Map of Ethiopia (scale 1: 2,000,000), 1973, Geological Survey of Ethiopia. Addis Ababa.

Feleke A., Landslide Hazard Zonation around Ameya Town Konta Special Woreda, South Nation Nationality People Region, Ethiopia Landslide Hazard Zonation around Ameya Town Konta Special Woreda, 2021, South Nation Nationality People Region, Ethiopia.

Takele M. M., The Geology and Geochemical Characterization of Tercha Coal, Southwestern Ethiopia: Indication for Energy Value, 2018.

Mengistie, T. M. (2018). The Geology and Geochemical Characterization of Tercha Coal, Southwestern Ethiopia: Indication for Energy Value. Addis Ababa University, School of Earth Sciences.