Addis Ababa university institute of technology

The development of process flow sheet for froth flotation method of coal deposit in the case of Yayo area, south-western ethiopia

By. Dagnaw Yimer Enyew

Advisor:

Dr. abubeker yimama (PhD)

Co-advisor

Mrs Enatfenta Melaku (MSC)

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Abstract

The aim of this project was the development of froth flotation flow sheet by using METSIM simulation software to create the flotation flow sheet for the Yayo coal deposit. The most popular technique for recovering and treating that portion of the coal preparation plant that has a fine particle size is froth flotation. The design of flotation technology undertakes is a challenging errors, since in data calculation and flow sheet developing were relatively simple to made and require frequent adjustment of instrument. This study, which was carried out in the development of the flotation flow sheet using METSIM simulation software, the proximate analysis value, ultimate analysis value, ash content and the calorific value were analyzed for the particle sizes, which were 500, 250, 125 and 63µm taken as a secondary data from the previous work studded on Yayo area in southwestern Ethiopia. From these particle size distribution 125 µm has more appropriate for high quality coal production and high percentage yield in this study based on METSIM simulation software. These were done for proximate analysis that simulated using simulation software the moisture content value of the coal is 21.25%, volatile matter values 22.3% and ash content 6.42%. The average value of the ultimate analysis of coal were 62.022% carbon, 4.558% hydrogen, 27.1653% oxygen and 12.87% sulfur obtained from the METSIM software simulated. The carbon content result obtained from METSIM simulation software is 79.49%, this shows the grade of the coal at the study area is bituminous coal.

Key words; flotation, flow sheet design software (METSIM)

Chapter One

Introduction

1.1. Background of the study

Coal is a physically and chemically heterogeneous sedimentary rock that burns easily and is made up of both organic and inorganic material. It is an organic rock that is predominately rich in carbon, with minor amounts of the inorganic elements hydrogen, oxygen, sulfur, and nitrogen. It is a solid carbonaceous substance that is typically found in stratified sedimentary deposits and is brown or black in color. The organic remnants go through a number of physical, biological, and chemical modifications (digenesis and catagenesis) both during and after the deposition of the plant remains in the sedimentary basins, which leads to a sequence of carbonizations. Unweathered plant material and peat are used as the first two materials in the series, which then progresses through lignite, sub-bituminous coal, bituminous coal, and anthracite in that order. The biochemical or physico-chemical stage of carbonization is thought to be the conversion of plant matter into peat and eventually charcoal (Behera et al., 2018).

Coal is available in most part of Ethiopia and majority part of Ethiopian coal is known for its low calorific value, high sulfur content, and high ash content. In order to improve or benefit from this poor grade coal and reduce impurities while still fitting its application, many technologies are used. Physical, chemical, and physicochemical beneficiations are recent methods for improving low-grade coal (Hangil Park et al., 2021).

These methods are used to boost the utility and economic viability of coal with high sulfur and ash contents. Techniques for mineral separation that use physical and chemical beneficiation are more efficient and have higher economic costs. In addition to being expensive, the chemical reagents used in these coal purification processes are hazardous and must be cleaned before discharge (Qianting Hu et al., 2015).

Physicochemical beneficiation is the most widely used and important approach in modern technology for the beneficiation of low-grade coal. Based on the hydrophobicity of coal particles and the hydrophilicity of mineral matters, physicochemical beneficiation is the most economical and effective separation of finely dispersed minerals to eliminate the inert components. Froth flotation is one of the most effective and cost-effective physicochemical processes for beneficiating coal. The fundamental tenets of froth floatation are based on the fine coal's surface wetting capacity, and their separation effectiveness is based on the attachment of pure coal to hydrophobic oil reagent surfaces and the detachment of impurities from those surfaces (Park et al., 2021). In order to improve the carbon content and calorific values of the Yayo coal deposits, the study will use froth floatation techniques of physicochemical beneficiation to separate impurity (mineral matter) from pure coals. The process flow sheet will then be developed using the software packages NIAFLOW and JksimMet. In which no Ethiopian industry practices the physiochemical beneficiation of coal by froth flotation and process flow sheet (O.-H.H et al., 2014).

A conceptual process is iteratively examined, changed, and reevaluated through a sequence of phases known as flow sheet development until it is workable. Although it can take many different forms (for instance, the plant may be built and then modified), it typically follows a pattern of laboratory work (which may be multiphase), piloting (which may also be multiphase), and demonstrative piloting in situations where the risks associated with commercialization are extremely high. A process needs to be directed toward an implementable, affordable flow sheet that will result in a marketable product, avoiding tangents that, despite being technically effective, are not economically effective. The procedure may be based on data from earlier operations or on a sound development program. Process development is typically done in tandem with engineering and economic studies (scoping, prefeasibility, feasibility, etc.), which are frequently carried out by an engineering firm. The engineering firm or the owner may request preliminary process design and capital and operational cost estimates from Hazen (Park et al., 2021).

1.2. Flow sheet development software

The mass and energy balance serves as the foundation for analyzing every chemical and metallurgical process. These estimates are necessary for technical evaluations, capital expenses, and plant design. METSIM is a multifunctional process simulation tool created to help engineers perform mass and energy balances on intricate processes. METSIM employs a variety of computational techniques to achieve the ideal balance between complexity, user time, and resource utilization. The goal of the computer simulation and the engineer's creativity determine the complexity of METSIM models that are produced. Before attempting to develop a model, it is advised that users become familiar with the program through the online help system. This online guide is structured so that the user first becomes familiar with the fundamental parts of the system and the steps required launching the application. Additionally, it describes the mechanics of entering process model data into the METSIM application as well as the specific data needs for the individual components. METSIM combines the complexity of cutting-edge engineering mathematics with the power of the most powerful computers. METSIM was created to make the most of APL's functional strength, work environment qualities, and interactive features. There is no longer a need for intricate text editing, file management, job control languages, or debugging software (Bartlett et al., 2021).

1.3. Statement of the problem

Some researchers have conducted research on coal froth flotation, but it is complex for understanding, so the development of a flotation flow sheet using the METSIM simulation software was required. In addition to this, the coal where is found in the study area has a high ash content, sulfur content and low carbon content, due to solve this problem by upgrading the coal quality and minimize unwanted particle, this study would be developed. The impurity in coal increases the environment would be polluted by releasing contaminants into the interior air and increases equipment damage by generating corrosion. As a result of the growth of industrial zones and the raising of living standards, Ethiopia's energy supply is not keeping up with its demand. The nation's cities, towns and rural areas are all experiencing an energy supply shortage. Due to Ethiopia's low calorific value and poor coal quality, local businesses including cement, metallurgical steel, and textiles are compelled to use imported coal, primarily from South Africa, at the highest cost in foreign exchange (USD). The idea is to upgrade coal using physicochemical beneficiation and build a flotation flow sheet for this process to use locally available coal, in order to fill this gap of high demand-supply and replace the imported coal.

1.4. The objective of the study

1.4.1. General objective of the study

The general objective of the study is to develop the process flowsheet for froth flotation method of coal deposit in the case of Yayo area, south-western Ethiopia.

1.4.2. Specific objective of the study

- To describe the Yayo coal deposit's physiochemical proximal and ultimate analysis.
- To evaluate the Yayo coal deposit based on screen size.
- To identify the grade of the coal present in the study area.

1.5. Scope of the study

The scope of this project was to construct a flotation flow sheet for the Yayo coal deposit for froth flotation process that is simple, legitimate and fundamental for those who need clear and trustworthy data to design a technique based on METSIM simulation software. This study focused on the Yayo coal deposit froth flotation method flow sheet development, which was designed for upgrading the quality of coal in the study area. Due to the high ash content of coal flotation method is more appropriate to concentrate at finest particle size distribution and the applicable technologies that enhanced the development flow sheet were applied based on METSIM simulation software. This project was studied from April to August.

- Developed an appropriate froth flotation flow sheet processes that enhanced defect coverage and raised the caliber of the finished coal products.
- Using METSIM flotation software technology, the process flow sheet for the froth flotation method of coal deposit was developed for the Yayo area.
- Proximate, ultimate analysis and identification of coal quality in the assessment of the coal sample using METSIM simulation software.

1.6. Limitation and challenges of the study

The limitation of this study was the accessibility of software, which was analyzed the given data and can't save the final result within the overall process. The performed task in the METSIM simulation software could not save and couldn't get again after shutoff and open on pc. It takes a lot of time and effort to accurately create the flow sheet in the METSIM simulation software for the flotation of the coal deposit in the given location using the froth flotation process. The process flow sheet development was limited by software. It can be challenging the software to construct flotation flow sheet for study area, because of they were licensed.

1.7. Significance of the study

The aim of this project employed METSIM simulation software to construct the froth flotation flow sheet for the Yayo coal deposit in order to improve understanding among investors and consultants. Technology was also used for data calculation and flow sheet creation. Conditions impacting the separation characteristics on the air table would be identified in the flotation process and the individual effects and interactions of the process variables would be characterized in detail. An outstanding method of informing the interest group about the layout of the coal plant in this project was the production of the beneficiation flow sheet of the coal deposit, which provided a step-by-step representation of each activity in the coal beneficiation process in ideal condition.

This project could be used as secondary data by a wide range of investors and researchers for their work. The study is crucial for understanding Yayo coal and gathering information for many readers. This flow sheet development was more significant since a well-designed process could be simple to understand in the coal flotation process, can be minimize capital expenditure, maximize long term profits and a good design process flow sheet pictorially and graphically identifies the chemical process steps in a proper sequence.

- Time saving.
- Easy control and monitoring
- For future upgrading of the process plant
- Illustrates the relation between major components.

Chapter Two
Literature review

2.1. Basic ideas of coal

Coal is an organic fossil fuel and sedimentary rock with fluctuating concentrations of carbon, oxygen, hydrogen, sulfur and nitrogen as well as trace amounts of other elements including mineral matter and methane that are present in the pore systems of the coal. It is a solid, brittle, combustible carbonaceous rock that was formed when vegetation broke down and changed due to pressure, heat and compaction. Old English "col" was the term for a variety of charcoal at the time and it is thought that this is where the word "coal" came from. In the northern area of England, for instance, it was called as "sea-coal" because it occasionally washed up on beaches. Coal is known by a variety of local names among Ethiopians, such as "Dengay Kassel" in Amharic and "Dhaka cile" in Oromiffa (ABDI, 2021).

2.2. Coal definition and its history

Heterogeneous in nature, coal is a mixture of biological and inorganic elements. Most of the organic components are derived from plant remnants that have undergone variable degrees of breakdown in peat exchanges as well as physical and chemical alteration after burial. According to the majority of coal deposits were formed in a peat swamp environment where a variety of plant species flourished, primarily reflecting the swamp's climate, water level and water chemistry (A. Meyers et al. 1982).

2.3. Formation of coal

The slow change of plant debris from peat to lignite, then through the higher ranks of coal to anthracite, was the most straightforward definition of the coal-forming process. Therefore, significant coal reserves first appeared during the Carboniferous period also referred to as the First Coal Age. Coal is made from peat, which is transformed into various rocks by biological and geological processes that apply pressure and heat to peat over millions of years after the plant dies. When dead plant matter builds up in peat bogs, aerobic bacteria quickly oxidize it, converting nitrogen-containing compounds into carbon dioxide (CO_2), methane (CH_4), and ammonia. When the medium is adequate (pH = 4), these aerobic bacteria quickly exhaust the available oxygen and die at the initial step of the process, creating acids as metabolic waste (Hughes et al., 2019).

Gytta, or proto-coal, is a gel-like substance that develops during the so-called biochemical stage of coal production, which is characterized by the decomposition of dead components under anaerobic conditions. Gytta is buried to a depth of 500-1000 ft at temperatures around 212 (100), at which point moisture and volatile substances are pushed out to form peat, which is a group of carbon-rich chemicals. The proto-coal undergoes physical and chemical changes as it progresses through the stages of rank development, which include deposition and sedimentation, compaction, and finally the conversion of plant and fossil remains into organic rocks. The geological process converts layers of organic rocks into the coal we know today by applying pressure and heat over a lengthy period of time. The coal deposits were created as a result of pressure and heat pushing plant waste under water over millions of years. Depending on the depth at which they were deposited, the coal deposits provide the energy. Phases that take place during the coal-formation process include peat, lignite, bituminous coal, and anthracite. Depending on the conditions to which the plant and fossil remains are exposed after being hidden under greater pressure and heat, these stages are required to go from lower ranks of coal to higher ranks of coal (Delhi et al., 2015).

Peat is the first stage in the formation of coal. At this stage, the breakdown of decomposed vegetable plants frequently produces water and carbon dioxide. However, when plant matter accumulates underwater without oxygen, just a small amount of the organic material is degraded. Peat therefore has a lot of water, little carbon, more contaminants, and a sufficient amount of volatile substances (Mooney et al., 2010). When peat is subjected to greater vertical pressure as a result of accumulating sediments, the second stage of coal formation, referred to as lignite, takes place. Similar to peat, it nevertheless contains small amounts of plant material. Because of extremely poor quality and increased ash and sulfur concentration it shouldn't be utilized before cleaning. As a result classified as low-grade coal with low carbon content that is only used to produce power; as a result, it worsens indoor air pollution and endangers the environment due to the high levels of ash and sulfur. The third and fourth stages of coal formation, known as bituminous and anthracite coal, occur when pressure is added to the phase to make it more compact, by which time almost all traces of plant life have perished. Because they have lower levels of moisture, volatile compounds, and ash, as well as higher carbon numbers with greater heat value and lower levels of incombustible gases, they can be identified as better-ranking coal (Shearer, 2002).

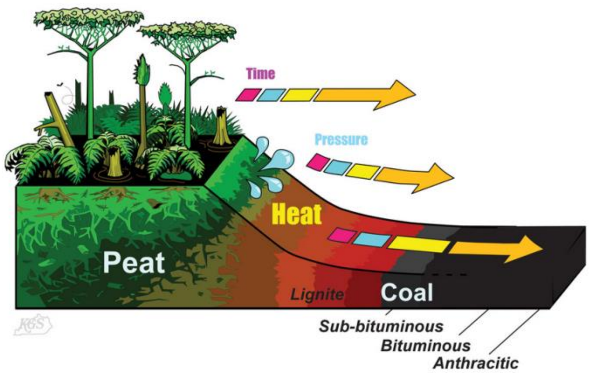

Figure 1. Coal formation

2.4. Coal classification

Different types of coal are ranked according to their attributes in coal classification. Coal can be divided into four primary categories based on the ASTM-D-388 standards, the degree of metamorphism, the elemental makeup of carbon, hydrogen, oxygen, nitrogen, and sulfur, and the quantity of thermal energy released. The following classifications for coal are lignite, sub-bituminous, bituminous and Anthracite coal.

2.5. Coal mining

Surface or open cast mining and underground or deep mining are the two primary methods of coal mining. The geological features of the targeted mine, the location of the coal seam or seams, and the equipment readily available at the time the mine is to begin operations generally decide the type of coal mining that is chosen. Due to the tools available when mining initially began, the bulk of coal is today extracted via one or more subterranean methods. Surface mining is quickly replacing underground mining as the preferred method for productivity and safety, though, as a result of the development of larger and more effective gear (WESTVILLE et al., 2019).

2.6. Production of coal

The largest coal productions were not confined to one region. The top five producers are China, the United States, India, Australia, and South Africa. The bulk of coal produced worldwide is consumed in the country where it was produced; only 16% of hard coal production is intended for the global coal market. China is expected to account for more than half of the rise in global coal production over this period, which is predicted to reach 7000 MT. According to DEMOZE (2007), it is estimated that 5200 MT of steam coal, 620 MT of coking coal, and 1200 MT of brown coal were produced. All of Ethiopia's cement companies were importing coal from South Africa and Russia as a result of the government's interference. However, domestic coal production and utilization by cement producers will total 615,722 tons in 2022G.c.

Coal gas is a byproduct of burning coal and is composed of a mixture of hydrogen (40%) methane (32%), carbon monoxide (7%), acetylene (2%), ethylene (3%), nitrogen (4%), carbon dioxide (1%), and miscellaneous gases (4%). It was initially produced as a byproduct of the coking process prior to the industrial revolution. Before the discovery of natural gas, the production of gas from coal increased significantly in the 1940s and 1950s. The demand for and acceptance of coal gas decreased as a result of the expansion of the natural gas industry. Natural gas has a content of 37 MJ/m3, compared to coal gas's 10-20 MJ/m^3 energy content (Ndlovu et al., 2020).

2.7. Coal occurrence

Coal, geothermal energy, and natural gas are among the many natural resources Ethiopia enjoys. Ethiopia is home to coal, which is related to lacustrine sedimentary rock and has a Cenozoic age. Greater coal reserves are ensured by this distribution of coal around the country, which serves as a link for creating industrial development. The study of coal seams must be a part of the search for new energy sources. Ethiopia's Achibo-Sombo, Gamo, Wellayita, Delbi-Moye, Jiren, Yayu (Geba basin), Lalo-Sapo, Chida, Chilga, Nejo, Arjo, Wuchale, and Mush valley Basins are among the locations where coal can be discovered (RAASK, 1985).

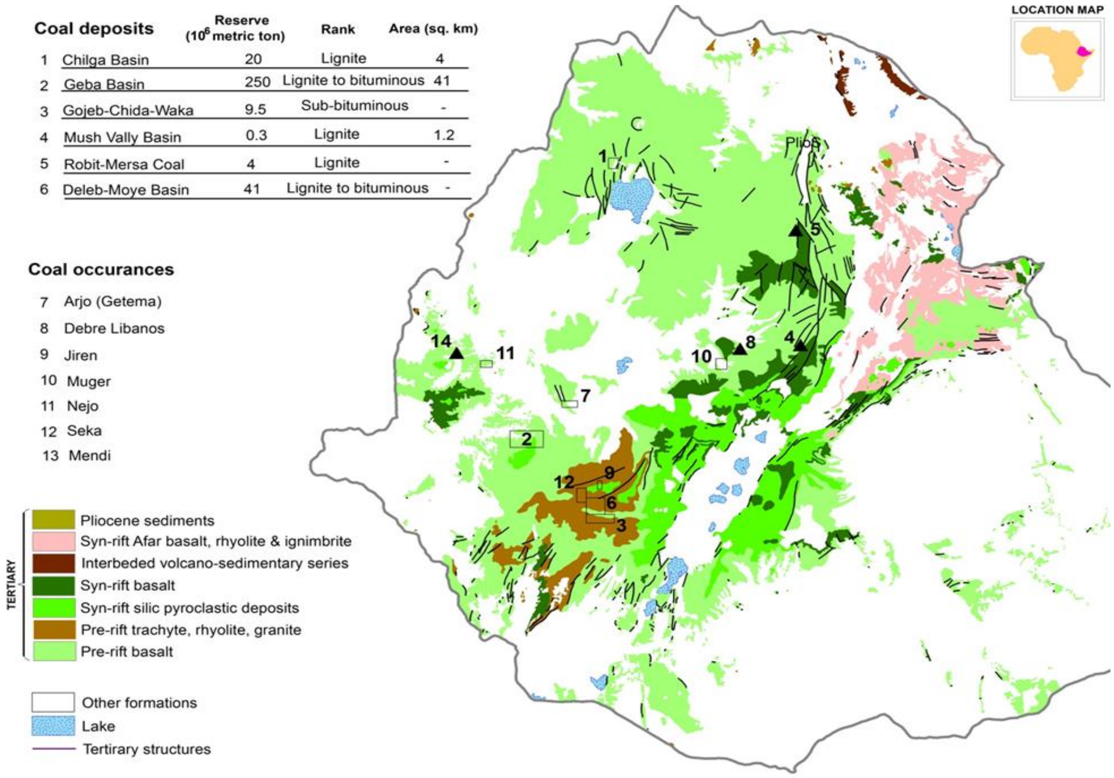

Figure 2: Coal occurrence map

2.8. Resource Classification and Reserve Calculation

Coal resources can be classified in a variety of ways, from a broad evaluation of a coal basin to the estimation of specific reserves found within mine workings. The outcome of a geological research of a coal deposit is the calculation of all sorts of coal resources. Each country has different standards for classifying its coal stocks and resources. A committee of the Council of Mining and Metallurgical Institutions of various countries uses standard definitions and methods of calculation for ore reserves that are probable, proven, and marketable. This agreement was approved by the Combined Reserves International Reporting Standards Committee on a provisional basis (mihretie et al., 2018). Coal thickness (m) area RD = total metric tons is the basic formula for estimating coal resources, RD stands for relative density.

2.9. Application of coal

The production of power, steel, cement, and as a source of energy for residential use are the three major applications of coal in the world. A feedstock for coal is also employed in the various chemical industries. A byproduct of refined coal tar can be used to create a number of chemical compounds, such as phenol, benzene, and naphthalene, using gasification processes to convert coal into gases (Abraham, 2018), for chemical industry, for the steel industry, for cement industry and others.

2.10. Coal beneficiation method

By eliminating inert material (mineral materials), coal beneficiation improves the carbon number to raise the calorific value of coal. In general, inert materials are mineral substances connected to coal that are producing high levels of ash, which are divided into inherent and external mineral substances. When coal is formed, the intrinsic mineral matter is linked to plant matter, which may or may not be coal making plants. However, the extraneous mineral matter is typically related to inorganic materials that are left over the coal beds and added to the coal particles that are loaded during mining. These materials are transported by water bodies, wind, and other mechanical systems. Because they have previously evolved a more extensive connection with the organic matrix of coal than external mineral matter, inherent mineral matter is more difficult to separate from its coal matrix. Utilizing low-rank coals presents a number of challenges because of their consistent high moisture, ash, and sulfur content. In order to increase their carbon content and calorific value, the low ranks hence require greater beneficiation before use. The main goals of low coal beneficiation are to decrease inert mineral matter particle size, enhance combustion behavior, decrease slagging and fouling characteristics, minimize capital expenditures, lower particulate emissions of pollutants and gases, improve combustion quality, and reduce transportation and storage expenses (J.A. Finch et al. 2007).

2.10.1. Coal physical beneficiation method

One of the most popular techniques for removing impurities from low-grade coal without chemical modification is physical beneficiation. Based on differences in physical characteristics including specific gravity, size and magnetic conductivity of the mineral materials and carbonaceous components of the coal, this approach is primarily used to separate coal and impurities. Low-grade coal cannot be cleaned using physical beneficiation techniques. The first method is more effective with higher-quality coal than with lower-quality coal. The second restriction is that coal gravity separation typically requires a bigger feed size greater than 0.5mm and only the pyritic sulfur is extracted. The third restriction is that chemically bonded minerals cannot be separated using this method. As a result, it is less successful for treating low-grade coals, especially those with high sulfur content, an excessive amount of slime coating, and contaminants that are chemically bonded and present in the coal matrix. Gravity separation and magnetic separations are two sub-techniques that make up a physical approach of low-grade coal beneficiation. The best approach for separating mineral impurities from coal particles is physical beneficiation, which is more efficient than other beneficiation techniques. The difference in surface wet ability qualities between coal-rich and mineral-rich particles of the coal slurry in an aqueous solution is what determines the separation efficiency. Because it is more successful and efficient at mineral separation, physiochemical beneficiation of low-grade coal has recently received more attention from researchers than other methods. Due to its efficiency and high production of clean coal that is separated from its impurities, the physiochemical beneficiation technology was chosen for this study. Oil agglomeration and froth flotation are two components of this technique (Janusz S. Laskowski et al., 2007).

- Froth Flotation

One of the most used physiochemical beneficiation techniques is froth flotation. This technique for purifying fine coal is based on the distinction between organic materials and inorganic minerals in terms of surface hydrophobicity and floatability. This technique's main idea is to separate hydrophobic coal components from hydrophilic mineral matter by adding chemical reagents (such as a mixer, collectors, and air application). This method mostly applies to fine coal particles (0.5mm). The hydrophilic mineral particles are left behind as tailings as the hydrophobic coal particles, which are affixed to air bubbles, rise to the surface of clean coal in the froth zone. For further investigation, the generated foam is collected or skimmed off, followed by filtering and drying. Oxygen functional groups, such as the hydroxyl, carbonyl, carboxyl, and phenolic group functionalities, are more abundant in low-grade coal. These functional groups increase the number of hydrogen bond sites with water molecules and create hydration films, which prevent the absorption of chemicals that form oily droplets, hence decreasing the ability of the coal particle's surface to be hydrophobic. The flotation of low-rank coal is especially challenging due to the presence of these oxygen functional groups. Chemical reagents are used by various researchers to improve the flotation process' performance. Kerosene, diesel oil, gasoline, pine oil, and oxygenated fuel oil are the chemical reagents used to float coal as collectors; the reagents used as frothers are methyl isobutyl carbinol (MIBC), methanol, polyethylene glycol, n-octanol, and oleic acid. The viscosity, molecular weight, and price of each reagent are taken into consideration when choosing one for the flotation of coal (PRATIMA et al., 2012).

- Oil agglomeration technique

Oil agglomeration uses an organic liquid to agglomerate the tiny particles from a mixture of coal and mineral materials. This beneficiation technique is based on surface qualities (wet ability). The fundamental idea behind oil agglomeration is that it produces big particle sizes (with low ash contents) made up of certain small particles by coating oil on hydrophobic surfaces of coal particles. Oil wets the hydrophobic coal particles, leaving the hydrophilic clay particles remaining for accumulation. Low-rank coal, including diameters below 38 mm, can be successfully treated using the oil agglomeration approach. Due to its excellent selectivity and separation efficiency, this method is utilized to remove inorganic particles from organic substances. The significant size increase that results from the oil aggregation process boosts coal recovery and calorific value. Additionally, since the process itself enlarges the size of coal particles during the beneficiation, it does not require any additional steps like palletization. The increase in clean coal particle size offsets the operational expense in terms of oil consumption. The type of coal, the type of oil, the particle size and the density of the slurry pulp are just a few of the variables that affect the oil agglomeration process. Additionally, pH, agitation speed, oil concentration (oil dosage), agglomeration duration and temperature are among the factors that are optimized during the process. Inter-particle bonds preserve the structural stability of the agglomerates, which are created as a result of inter-particle collisions, adhesion of the particles coated by the bridging liquid and agglomeration. However, due to the high expense of oil's acceleration, there are currently no practical applications for this approach. However, research is being done to better the processes by identifying clean coal's greater performance in order to comprehend the degraded economic processes (Boulton, 2015).

- Gravity Separation

The impurities from coal are separated using the gravity separation technique of physical beneficiation methods, which uses the specific gravity-based differential on either water or in a dense medium. The fundamental issue with tiny and ultrafine coal particles is their large specific surface area, small mass and high surface energy per surface area. These reasons make gravity separation more effective in treating coarse-sized coal particles than fine- and ultrafine-sized coal particles. The separation of fine coal particles from its mineral particles uses an enhancement accelerator to get over the weak gravity impact of fine and ultrafine particles. The improved gravity separators employ a centrifugal field that is mechanically applied. Using appropriate liquid mixtures like bromoform (2.9 g/cm3), benzene (0.9 g/cm3) and tetra chloroethylene (1.6 g/cm3) to form the specific gravity ranges of 1.3 to 1.8, coal particles are gravity separated with a suspension of water and a heavy mineral, most frequently magnetite (particle size 44 m). The sink was once again added to the following higher density liquid after the float and sink portions were separated. The clean coal that floated when recovered from the beakers and the ash-forming minerals sank beneath the beaker because they were made of heavier metals. A specific gravity of 1.7 g/cm3 was optimized through experimental research after the outcome of the ash yield mineral was reduced from higher to lower values of specific gravity solution (Adam, 2021).

- Magnetic Separation

Because the majority of the sulfur- and ash-containing mineral matter in coal is paramagnetic and can be separated from the remaining diamagnetic carbon, magnetic separation of coal beneficiation is based on the magnetism properties of coal. Since magnetic separation is a dry process, the coal particles must be dried before beginning. Because coal separations demand a greater magnetic field that behaves as a magnetic dipole, the magnetic susceptibilities are relatively low. The majority of the time magnetic separation procedures were effective for coal's iron-containing components. According to Nyoni S. et al., a high-gradient vibrating magnetic separator was utilized together with small size fractions of coal particles to explore the magnetic separation of coal particles in upgrading the sub-bituminous coal to obtain clean coal. Regardless of the particle size, the outcome of dry magnetic separation can efficiently remove various dangerous trace elements in raw coal, including Cd, As, Pb, Se, Hg, Mn, and Cu. The effectiveness of desulfurization and de-ashing varies with the range of particle sizes. Due to the fact that the magnetic separation process of coal beneficiation is typically more restricted to coal that only contains more magnetic metals, particularly iron, magnetic separation is not an efficient and effective approach for the separation of clean coal from its impurities of mineral materials. If an augmented gravity field is used to overcome the sluggish particle speeds, gravity-based separation of clean coal from contaminants is capable of more selective separation methods than magnetic separation (PRATIMA et al., 2012).

2.10.2 Methods for Chemical Beneficiation

Both inorganic and organic mineral materials are removed from coal using the chemical beneficiation method. In order to prevent issues with liquefaction, gasification, combustion efficiency, and emissions reduction of airborne pollutants, this approach effectively minimizes the ash content as well as the removal of harmful minerals. With the aid of chemical solvents used to remove mineral materials like finely divided minerals and particles that are tightly attached to the coal matrix, low-grade coal is also treated using this process. Mineral alkali reagents (NaOH, Ca(OH)2, KOH) and acidic mineral (HCl, HF, HNO3, and H2SO4) are the chemical solvents utilized in the leaching process. The leaching procedure impacts the coal minerals directly without changing the coal's natural structure and is quicker for the liberation of minerals. Chemical beneficiation procedures aren't used frequently in the commercial sector since they require expensive solvents, and dewatering costs more than water treatment and regeneration solvents combined. Alkali and acid leaching are the two primary forms of leaching used in chemical beneficiation techniques (PRATIMA et al., 2012).

2.10.2.1. Alkali Leaching

By removing the majority of the mineral-rich elements, alkali leaching is a technique for demineralizing coal. Alkali reagents, which have a strong affinity for coal minerals and the capacity to pierce the internal coal matrix, work in concert to produce this effect. During alkali leaching, silica, alumina, and clay-containing minerals present in coal are reacted with alkali reagent to create hydrates of alkali-bearing silicate, aluminate and alumino silicate. The presence of the hydroxyl ion of the leachantes, which has a strong affinity for the clay-bearing minerals, is the primary cause of the alkali reagent attacking coal principal minerals. Turkish coal was examined by Dhawan H and Sharma DK using aqueous caustic leaching to remove the minerals from the coal under settings of 0.1 to 1 M concentration. The aqueous caustic solution fluctuates in temperature between 100 and 180 throughout the course of 4 to 16 hours. Last but not least, the coal's ash content and total sulfur content is decreased from their initial values (PRATIMA et al., 2012).

2.10.2.2. Acidic Leaching

The most significant impact on the demineralization of metal ions in coal that is solubilized in acidic media is caused by acid leaching methods of coal beneficiation. While the clay-containing minerals are not dissociated by the acidic leaching process, other minerals such carbonates, Fe2O3, and sulfides have been demineralized. According to the Behera SK et al. research, HCl can dissolve practically all minerals, including carbonates, phosphates, and sulfates, which are commonly linked to important elements like Mg, Ca, Al, Fe, Ti, and K. However, it can only dissolve silicates, certain alumino-silicates, and pyrites in coal. However, all types of mineral matter can be reacted with HF acid, with the exception of pyrite and nearly all of the reaction products of water-soluble minerals. With the help of other mineral matter, this sort of leaching dissolves the main clay minerals and alumino silicate mineral complexes. Most of the substances that form minerals at greater HF concentrations are insoluble, such as CaF2. As a result, because fluorine atoms are present in HF, it has a strong oxidizing effect and is readily reacted with coal's mineral content. Quartz dissolves more readily than kaolinite during HF treatments, while it can also efficiently dissolve both minerals. In order to remove the kaolinite minerals, low-grade coal was more thoroughly leached with HF than with other acidic leachants at 65° and 3-hour contact duration (PRATIMA et al., 2012).

2.11. METSIM simulation software

Every inorganic and metallurgical chemical process that is currently known could be simulated and modelled using the potent software METSIM. Businesses all across the world use METSIM to plan model and manage a variety of processes, from mining to tailing and all in between. WILD can be used to create a process flow diagram in its most basic form. The operations of METSIM modules and embedded units include mass and energy balance for static or dynamic mining, storage, mass extraction, material handling, milling, beneficiation, hydrometallurgy, pyro metallurgy, gas and steam processing, and waste management processes. Only a few examples of the information provided on the material to be processed include mineralogy, particle size analysis, size class specific or multi-component size analysis, wash ability data, mechanical, physical, and thermodynamic properties. METSIM was developed using the software application. Application allows users to software everything they can imagine without having a computer science degree because it is less complex and easy. The ability to impute and desply data for viewing, analyzing, and monitoring is also provided via METSIM's ability to link to excel and other applications that employ Dynamic Data Exchange (DDE). METSIM may answer simple or complex metallurgical and process-related questions, relieving the user and engineer of the need to use time-consuming spreadsheets (Bartlett J. et al., 2014).

Chapter Three

Methodology

3.1. Research design

This chapter would be detailed the models that were used to simulate the froth flotation process by using METSIM simulation software, in a single and double flotation cell circuit. Firstly the material mass balance for a double cell would be performed, which introduce the two route of recovery. The oiled particles of the coal were more readily attached to the air bubbles and were floated to the surface as froth. The froth was then skimmed from the slurry and cleaned. Following this an air recovery model reflecting froth stability would be described in detailed. which was used for this project and a comparison type of research, would have been done in the earlier research that was carried out on the study region in order to compare the results would have been used as a secondary data.

3.2. Types of Data and sources

To accomplish the goal of the study, the researcher would have utilized secondary sources of data. The various books, yearly reports and previously completed research projects about the coal froth flotation process on the Yayo area, south-western Ethiopia were included in this data repository. The previous research were worked by using the equipment required includes the following: Universal Hot Oven, Kjeldahl Digester, Silica crucible, Desiccators, Muffle furnace, Jaw crusher, Centrifugal mill, Sieve Shaker, Wedge flotation cell, Adiabatic Bomb calorimeter and Flash CHNS/O analyzer. I have taken the input data from this previous worked research as a secondary data and develop the froth flotation flow sheet or circuit by using METSIM simulation software application, finally the end result were compared.

3.3. Methods

The secondary data was gathered from published studies on the Yayo coal deposit that was based on ASTM D-2013. Screen size, input mass and the reagents employed would be all been included in the study. The required data were used the aforementioned specified parameters. Using this data, METSIM simulation software was used to simulate a coal sample. Flow sheets could be created by using this software. The first information imputes for the METSIM-created circuit flow sheet were shown in Figure 3 below. The flow sheet includes common unit operation symbols that could be quickly recognized as a stockpile, a screen, a jaw crusher and conveyors. All common procedures were covered by the unit operations that were part of METSIM, along with a number of exclusive unit operations. Unit activities were joined by streams to show the direction of material movement. From this point, the user has complete control over the amount of realism. Bradford Breakers were used to reduce the size of the particle and simulate run-of-mine coal as it was received from the colliery. The coal was broken by gravity impact, discharged through the plates to a size of roughly 500, 250, 125 and 63 μm and then screened into -500 and +63 μm fractions once it has reached the necessary size. The flotation cell Separators, which were typically of the deep bath type, received the -500 to +63 μm materials separately. The primary separator in the flow sheet transfers the floats to the secondary unit, which creates medium and high-grade coals. A Bradford Breaker equipped with perforations received the sink product from the primary separator and reduced the middling to -500 for retreatment in the Baum Jig Section while rejecting the hard shale.

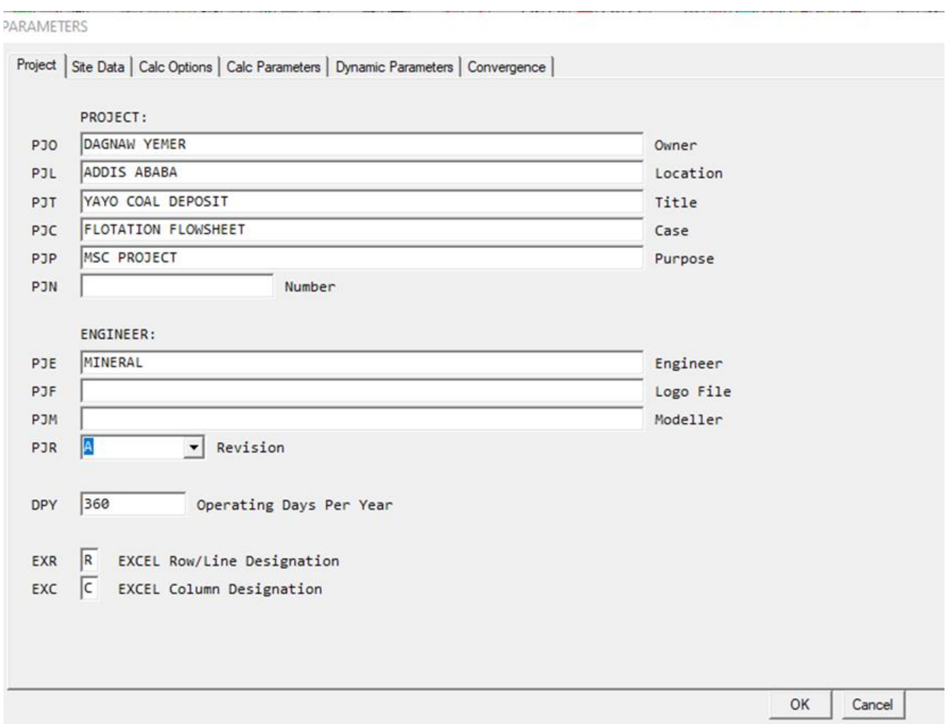

Figure 3. The first filled parameter data on METSIM software

Spraying screens were used to filter the separator products before flotation machines were used to remove the fine coal from the effluent. Without this flotation stage, the fine coal would disrupt the natural media's specific gravity range and result in a significant circulation load of coal particles. The media was a highly regulated percentage of the main flotation section's tailings in terms of density and size (+125, -500 mesh). Baum Jigs were used to process the +125 portion from both Bradford Breakers and the clean coal was screened into different size categories. Wedge bar screens, followed by a centrifuge for additional dewatering before cleaning the coal. The product were pumped to large diameter settling cones for treatment in the froth flotation section the underflow from the 63µm wedge bar screen. The waste shale from the secondary Bradford Breaker was blended with the waste from the Baum Jigs and utilized as filled. The settling cones' supply for the centrifuge was siphoned off to feed the flotation section. At this point, the reagents were added and a combination of cresylic acid-creosote, which serves as a collector and frother was employed. Utilizing flotation machines with four-bladed froth paddles, the separation was accomplished.

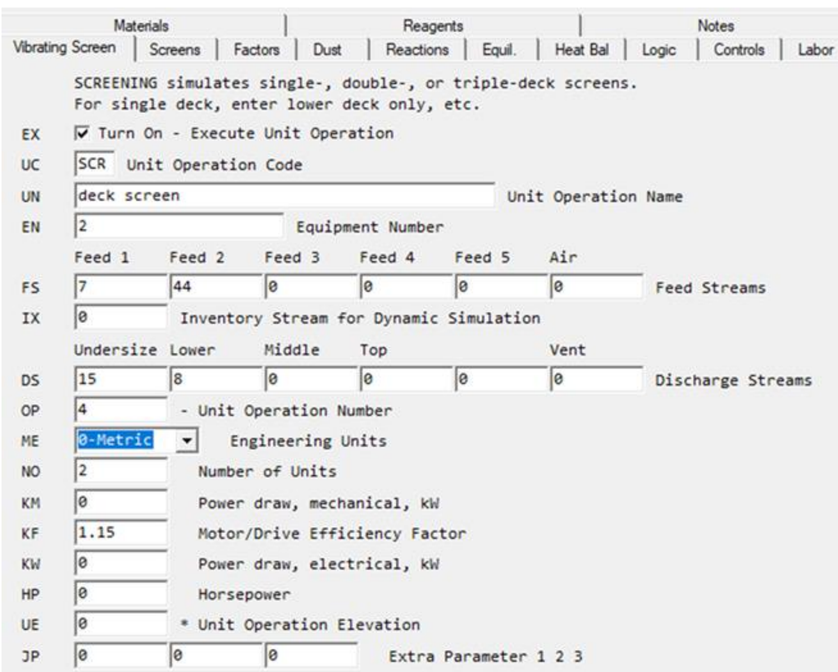

Figure 4. Screen data imputed in to METSIM software

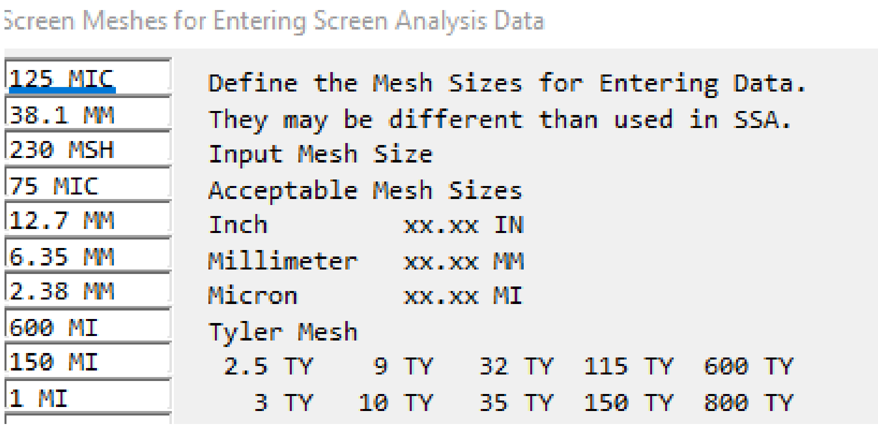

Figure 5. Screen data impute 125 µm

Screen size distributions, equipment dimensions and other important process models were chosen using METSIM simulation software, which also established the flow sheet and equipment kinds. The models (using plant data) were simulated a specific operation; the models simulate a circuit and forecast the performance of the circuit; and the models update coal data and provide the results as annotated flow sheets, tables, and graphs on the screen or in printed reports. Particle size, feed rate and reagent addition were among the characteristics that needed to be tuned during the flotation process. In this study, the working parameters were optimized based on the one variable at a time theory. The highest mineral removal efficiency was measured in this study as the response and the key parameters included feed rate, collector and frother dosage and particle size.

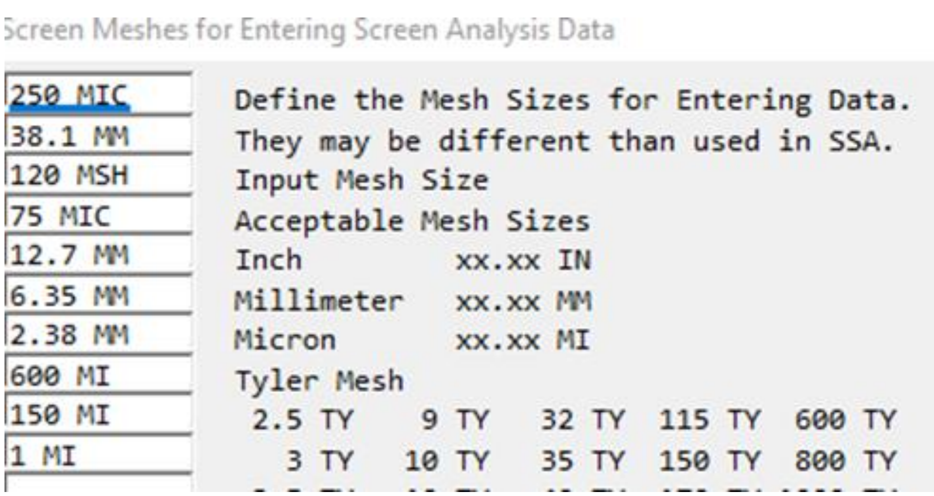

Figure 6 shows the screen information inputs for the 250 µm Metsim simulation software.

Figure.6 shows the screen information inputs for the 250µm in METSIM simulation software and channel or core sample of coal was analyzed using METSIM simulation software in accordance with international and national standards for coal analysis. This was done as part of the development of a flow sheet for the beneficiation of coal deposits at Yayo area.

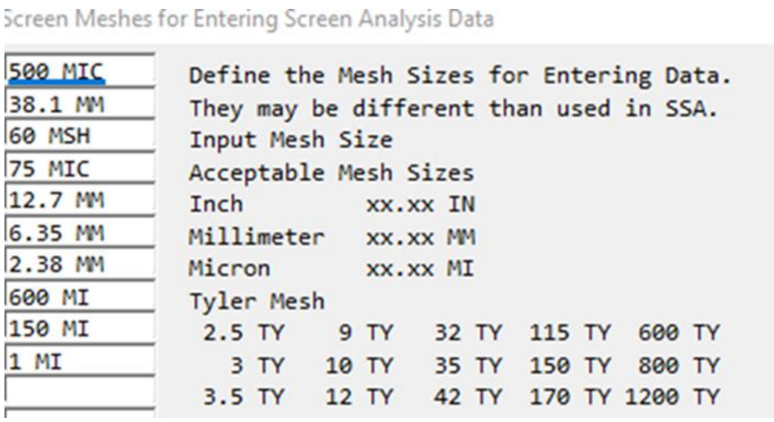

Figure. 7. Shows the METSIM program input data for a selected 500 μm screen size

Figure.7. shows the screen information inputs for the 500 μm in METSIM simulation software and this were adjusted to agree with the calculated ash content. This data were used as the input to the flotation separation module. The product of the flotation separation module products were calculated and form the final product.

3.3.1. Ultimate analysis

For the final analysis, METSIM simulation software modeling program calculated the percentage mass fraction of the key elements of coal, including carbon, hydrogen, sulfur, nitrogen and frequently by difference oxygen. The results of the final analysis are coupled with the coal's calorific value to perform combustion calculations, such as the estimation of coal feed rates, calorific value, and sulfur emissions.

3.3.2. Proximate analysis

The proximate analysis were identified the moisture content, volatile matter (VM), ash and fixed carbon in a coal sample by using METSIM simulation software with automatic display starts from the given data input. It was the most fundamental and widely utilized kind of coal assessment and it forms the basis of many coal procurement and performance prediction indices employed by utility operators. The METSIM simulation software was used to determine the total moisture content of the given data for coal sample. A coal sample weighing 600 g was altered to replicate the flotation process and the raw coal moisture content measurements were yielded with varied findings. The Standard sieves were used to screen the concentrate and tailing on 500 μm (60 meshes) of METSIM simulation data.

Chapter Four

Results and Discussion

4.1. Coal characterization

The findings of the chemical analysis of the coal sample were presented and discussed in this chapter together with the results from the METSIM simulation software. The results of this software's chemical analysis of the coal sample were presented using tables and figures. The amount of fixed carbon, volatile matter, moisture content and ash content were all taken into consideration. For the final study, the coal's composition in terms of carbon, hydrogen, nitrogen, sulfur and oxygen was also evaluated. According to the outcomes of the proximal and ultimate studies performed using the program, the main factors that determine coal quality and important coal parameters have been discussed.

4.2. Comminution of coal

As mined coal must be crushed and sized to manageable particle size for feed a particular plant. This chapter was described the methods for breaking particles and sorting the broken coal into sizes appropriate for farther processing. The study's flow sheet demonstrates the ethical behavior in the Yayo coal region of south-western Ethiopia. The main objective is to create a flotation flow sheet and to maximize the clean coal recovery. The flow sheet includes three steps of treatment for the different size ranges, including Baum Jigs for the -250, +125 μm fraction, Dense Medium for the -500, +250 μm fraction and froth flotation -125, +63 μm fraction. In this case -125, +63 μm fractions were appropriate for high coal quality cleaning. In addition to recovering low-ash coal fines, flotation was a crucial component of the flow diagram for preparing coal flotation tailings for use as separation media in dense media as well as to improve the disposal of fine waste or tailing. The figure shown below ware a comminution flow sheet that developed by Agge flow software to minize the coal size for appropriate manner for coal cleaning and to develop the froth flotation flow sheet with METSIM simulation software.

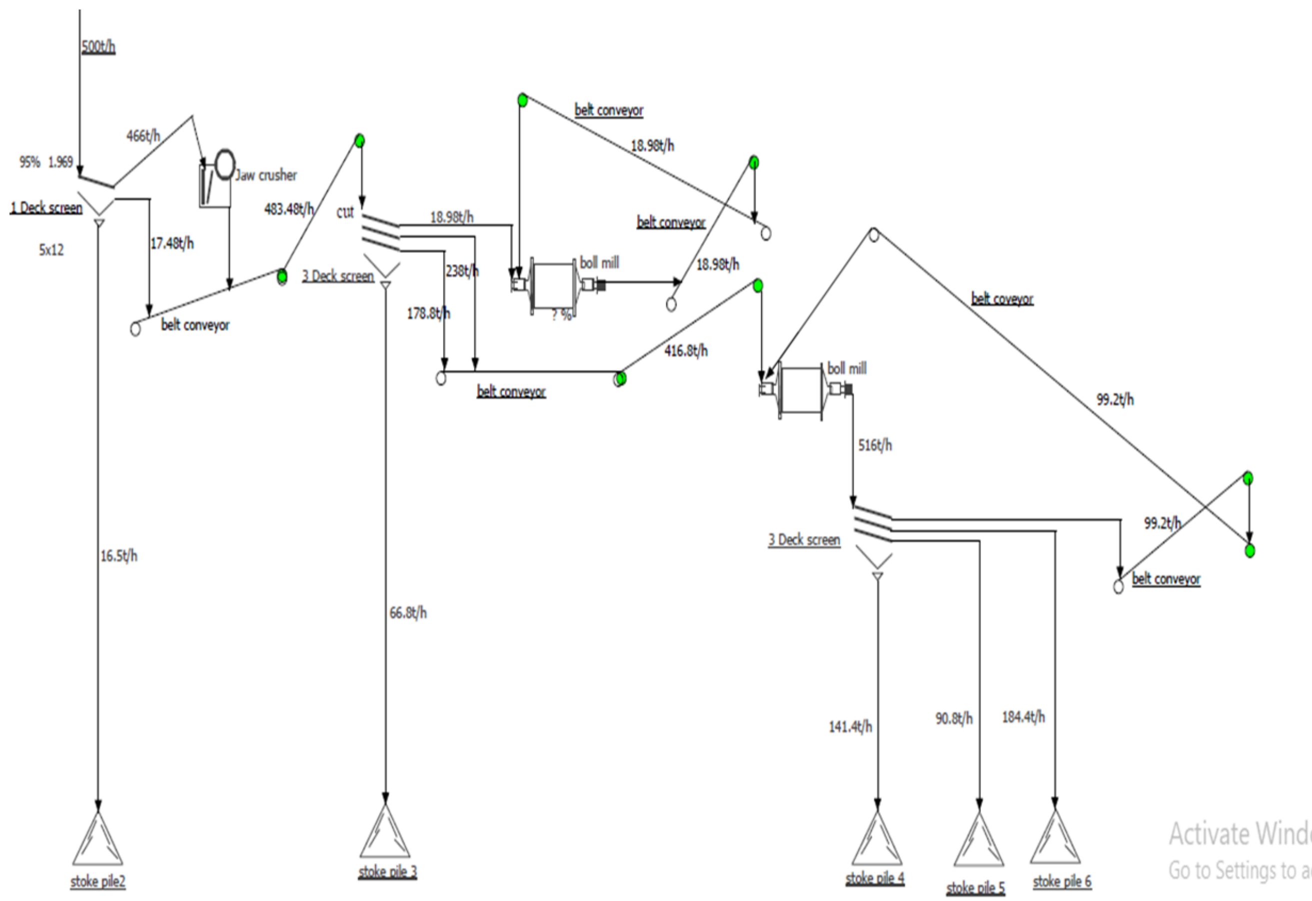

Figure 8. Shows a coal comminution flow sheet created by the software program Agg flow.

The above figure 8. Shows the flow sheet of coal cominution circuit with in Agg flow software, which was associated with coal characterization procedure in order to have information on the size reduction of a coal particle and the final distribution of ash. This model could serve as a basis for a complete cominution model which could take in to account the carbon and the inert content of coal. From this flotation flow sheet could gotten information on the size reduction of a coal particle distribution.

4.3. Circuit Design and Simulation

With the use of the METSIM simulation software, the flow sheet for froth flotation process were developed and the simulated the circuit configurations. In Figs. 9. provided a succinct description of these circuits. With the inclusion of a crushing machine, these flow sheets were fairly typical of contemporary coal preparation operations. The jaw crusher reduced feed with a top particle size of 500 µm to 125 µm. The crushed product was floated at a 125 screen aperture to size it into - 250 and + 125 µm streams since Yayo coal was produced medium quality coal at the primarily composed of + 125 µm particles in the previous work and also in this study has occurred this the medium quality coal in this fraction. The first process option used flotation to purify the -250 and +125 µm fraction, which included the highest levels of ash and sulfur, before being discharged into tailings. A classifying cyclone was added to the first process option in the second flow sheet (Fig. 9) to separate the -125 µm stream into -125, + 63 µm fractions. Here, the second and third process alternatives were chosen, in which the -125 + 63 µm fraction was handled by a spiral and a concentrating table, respectively. Since coal only makes up 3.13% of the total feed mass and has a weak flotation response, it was discarded to -63 µm coal streams into tailings without further processing.

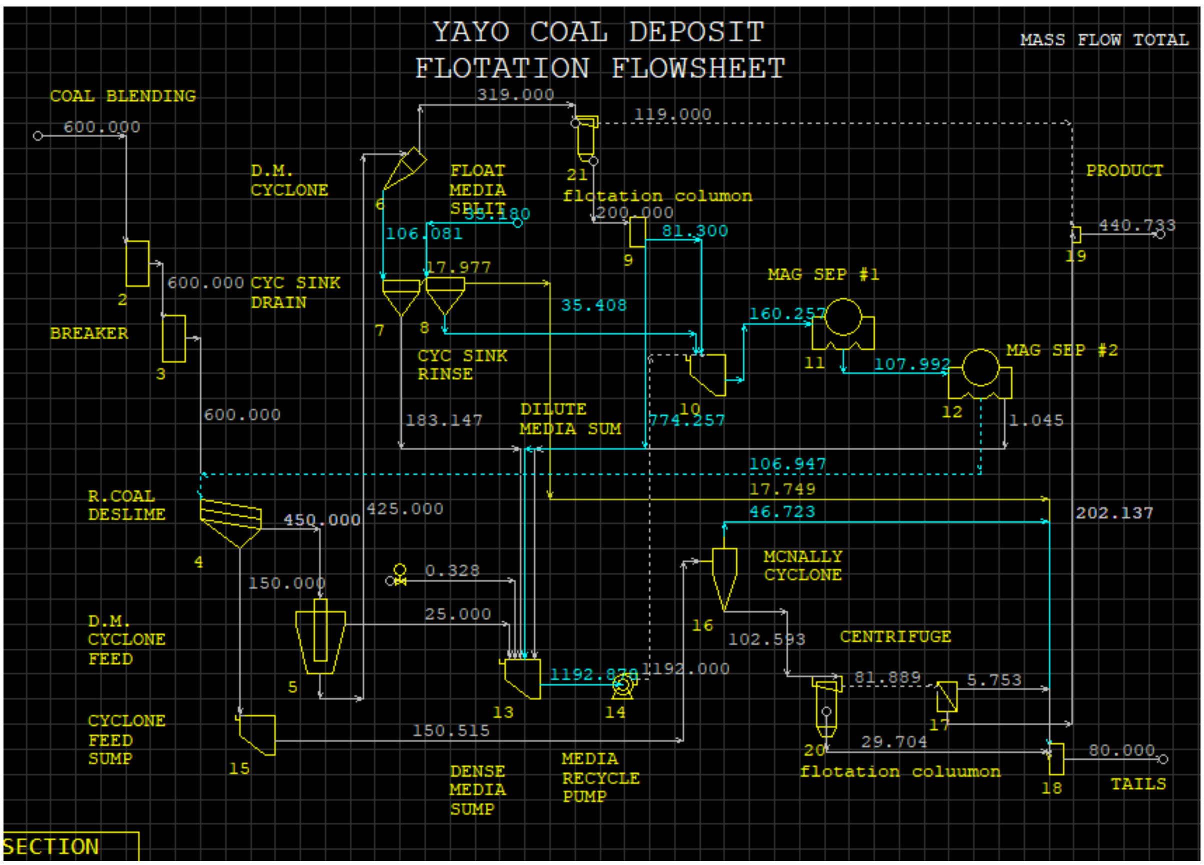

Figure 9. Developed flotation flow sheet at 500 µm

The separation of concentrating devices' screen sizes were varied during simulations between their realistic ranges of -500 µm and +63 µm for froth flotation. All models were run using a 600 t/h plant capacity, which was selected for comparability and based on the existing rates of coal production in the various coal zones of the Yayo coal field. The yield, ash and sulfur contents of clean coal and plant tailings were produced. The expected yield-ash and yield-sulfur curves for the aforementioned circuit designs were plotted using the chosen data. The choice of the process option was made with the goal of maximizing yield while still satisfying the ash and sulfur criteria of the end customer.

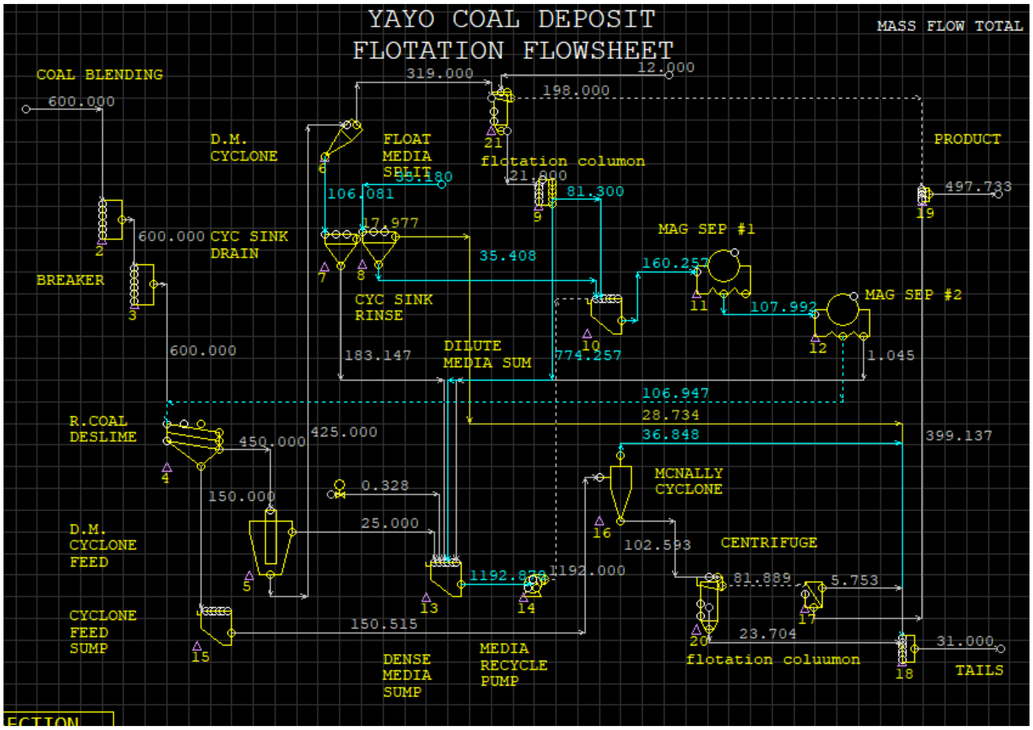

Figure 10. METSIM simulation software application flow sheet at 250 µm

	Wt.Frac.	Mol.Frac.	ST/HR
cCOAL	0.6364700	0.8884083	4.7833378
cASH	0.3218850	0.0898163	2.4191
cSUL	0.0416449	0.0217752	0.3129791

Figure 11. Percent compositions of ash, carbon and sulfur at 250 µm

This shows the results of size distribution of coal at 250 µm was produced 497 t/h cleaned coal product and 31t/h tailing. The dominant size fraction of the coal was 63.64% weight fraction with a yield of 32.19% ash content and 4.16% of sulfur content. This high content of micro-fine particle would increase the difficulty of flotation by attachment of high ash particle on coal surface.

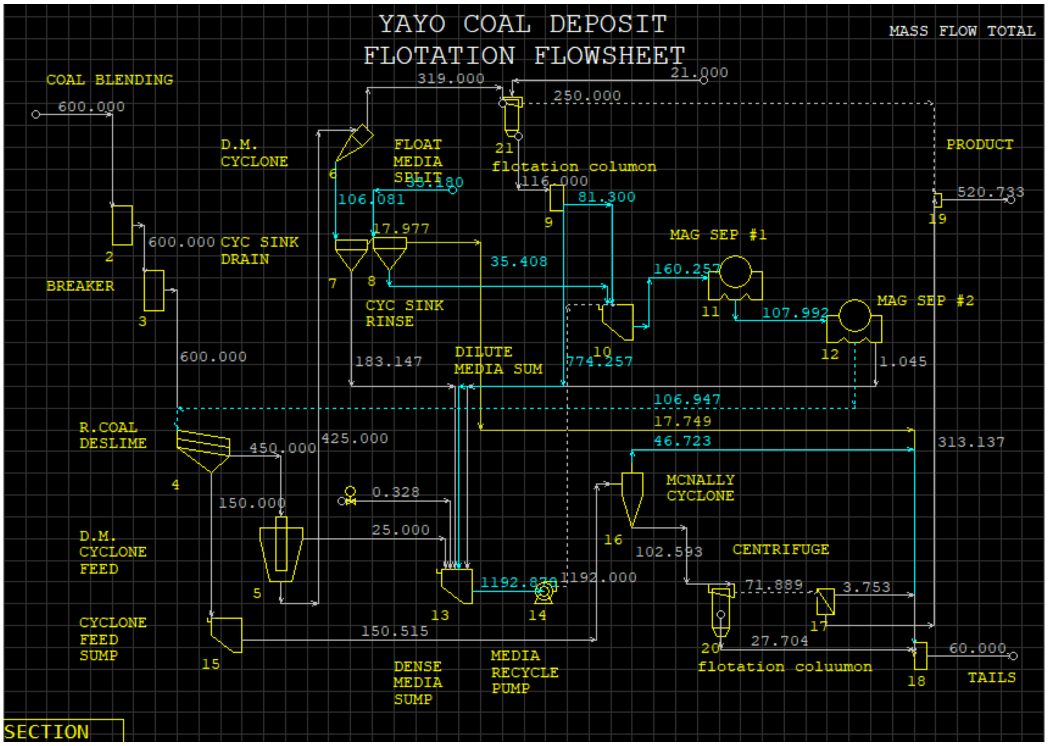

Figure 12. Developed flow sheet at 125 µm screen size

	Wt.Frac.	Mol.Frac.	ST/HR
cCOAL	0.7947556	0.9424144	158.95113
cASH	0.1621182	0.0384291	32.423654
cSUL	0.0431260	0.0191564	8.6252182

Figure 13. Percent compositions of ash, carbon and sulfur at 125 screen size

The percentages of ash content, clean value, and sulfur content were 77.62%, 17.76%, and 4.6%, respectively, according to METSIM software. The calorific value of the Yayo coal sample, as determined by the results, was 77.62%. This demonstrates that increasing the calorific value of the specified sites through beneficiation using the froth flotation process is an appropriate strategy. Because Yayo coal has low levels of impurities and ash, which hinder the coal's ability to burn efficiently, it has a high calorific value and releases a lot of heat. The METSIM simulation software was used to generate the sulfur content values, which were 520t/h for cleaned concentrate coal sample. Compared to the 500 µm and 250 µm screen sizes, the 125 µm screen size has the highest sulfur content. Due to the development of highly sulfuric ash, the high sulfur content in coal was reducing the heating capacity of the burned coal.

4.4. Proximate analysis

Using the METSIM simulating software the proximate analysis were performed which were the inherent moisture content, ash content, volatile matter, and amount of fixed carbon calculated. The results of the coal proximate analysis were presented in tables and graphs. The analytical result shown below discloses the standards and purities of the coal; the most important one to determine the quality of the coal was its calorific value. It was crucial to perform a proximate analysis to determine the coal's quality and rank. The results of each sample size analysis were shown on the page after that.

4.4.1. Determination of Moisture Content

Moisture, gas and gas-liquid inclusions linked to both solid organic matter and solid inorganic matter make up the coal's fluid matter. Higher-rank coals often have lower values for this characteristic, whereas lower-rank coals typically contain more of this physically and chemically adsorbed water in them. The moisture content measurement used in the display recording was obtained from the METSIM software analysis findings. The table and graphic below show the average values for each size. The coal's moisture content ranges from 15% to 21.02%, with a total average value of 17.19%; when compared to the other sample sizes, sample size 500 µm has the greatest moisture value and sample size 63 mm has the lowest. Yayo coal frequently had a high moisture content, which might reduce coal burning efficiency and prolong the evaporation process. Since combustible material was replaced, sample size 500 µm has a higher moisture content, which lowers the heat content per kilogram of coal and increases heat loss from evaporation and vapor superheating. In contrast, sample size 63 µm has relatively lower moisture content in terms of percent and has less of an impact on the heat content of the coal. For coal to be stored and used effectively, more moisture must be present since too little moisture makes coal heavier to transport, has a lower calorific value, and is more difficult to handle.

Table 1. Moisture content in percent from software

Sample size	Moisture content
500	21.02
250	16.72
125	16
63	15

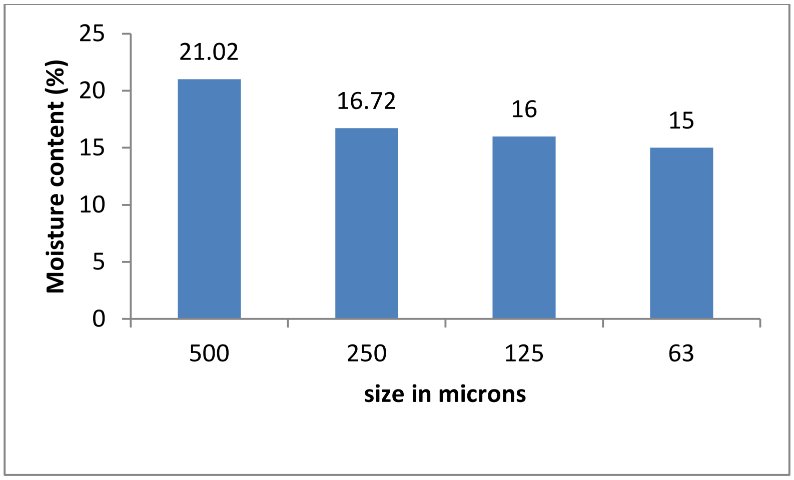

Figure 14. Moisture content vs size

4.4.2. Determination of Volatile Matter

The results in Table 6 were derived from METSIM simulation software, which reported the percentage value of the outcomes for each sample size. When coal is heated to a high temperature, combustible gases like steam and vapor, as well as incombustible gases like carbon monoxide and hydrocarbons, are released as volatilities. The outcome shows that the highest volatile matter concentration values have at the highest coal particle size. The amounts of combustible gases increased, the amount of fixed carbon decreased, and as a result, coal's heating value declined.

Table 2. shows amounts of volatile matter derived from METSIM

Sample size	Volatile matter(%)
500	22.3
250	20
125	19.8
63	19.5

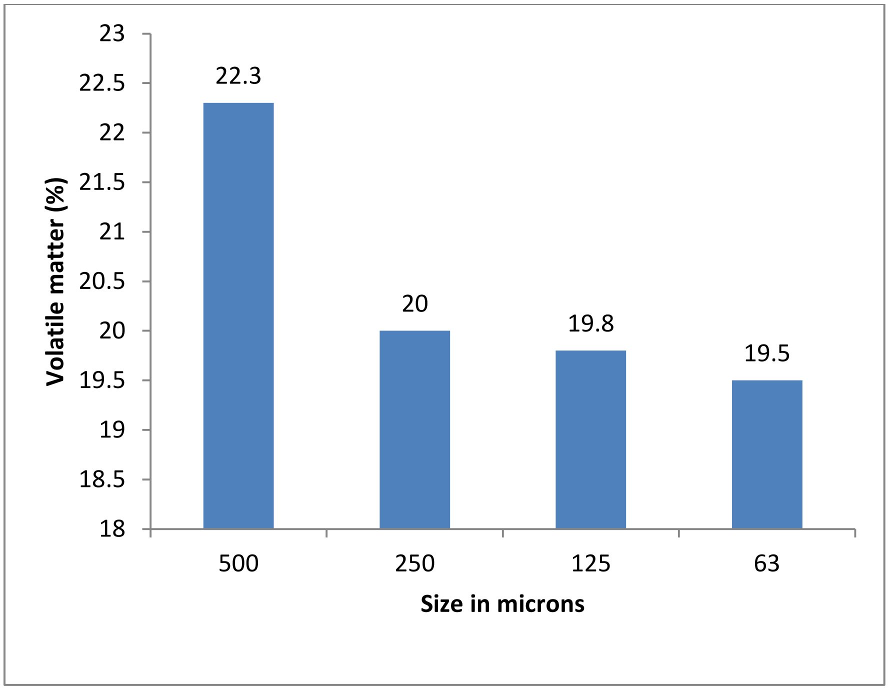

Figure 15.shows Volatile matter graph

4.4.3. Measurement of Ash Content

The average value of each sample size for the analyzed coal sample's ash concentration, which was determined using METSIM modeling software, ranged widely from (3.2% - 24.5%) and averaged 11.58%. With the exception of samples 500 and 250, the result demonstrates a fairly wide range; the bulk of the coal sample has the greatest ash level. Reduced burning capacity, higher handling costs, decreased combustion efficiency, and significant slagging were the results of raising the ash content. The type and design of the ash management system used in the coal-utilization process depends on the amount of ash and how it behaves at high temperatures. Coal ash gets sticky at high temperatures and eventually melts into molten slag. The quality or rank of coal drops as the quantity of ash content rises since there are more impurities present, which - lowers coal efficiency. The amount of unburned material was little or the quantity of impurities, such as rock, dirt, and others, were comparatively present in minimal amounts as the ash content decreased. When the ash content was rises the coal volatility falls and vice versa. Additionally when moisture content was increases the coal volatility also increase.

Table 3. Size distribution of sieving for the product coal

No	Size fractions, µm	Yield (%)	Ash content (%)
1	500	19.26	6.95
2	250	24.16	8.93
3	125	35.15	6.42
4	63	21.43	6.78
5	total	29.08	29.08

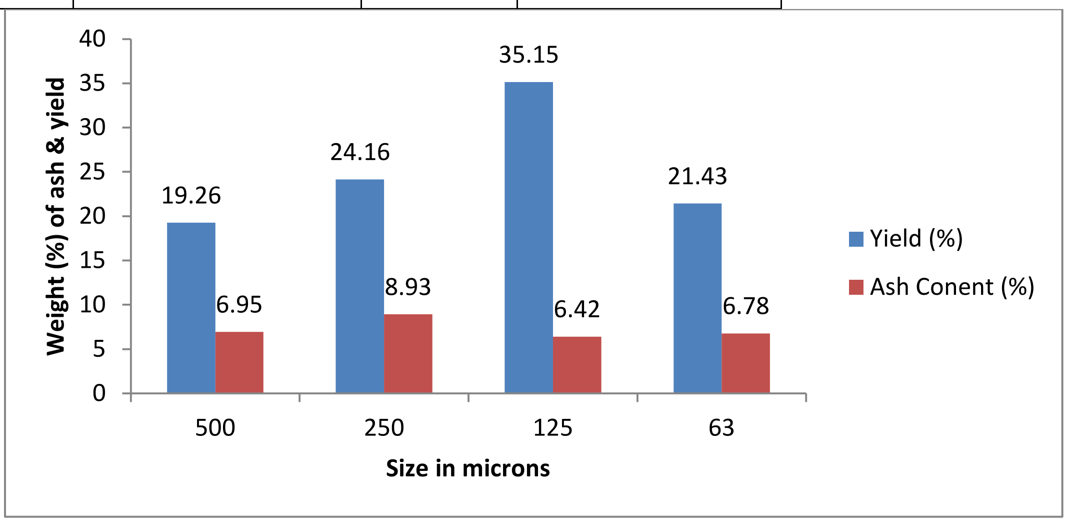

Figure.16. Shows size distribution on coal product

The above figure 16. Shows that sample sizes 500 and 250 have relatively high amounts of ash content, which indicates that there are many unburned materials present. These sample sizes would have relatively low carbon contents and provide little heat energy, but sample sizes 250 and 125 have relatively low amounts of ash content, which suggests that the coal is of moderately high purity. In general, the high percent yield obtained on particle size 125 microns, which were low ash content and high carbon content.

4.4.4. Fixed Carbon Amount

The heating value of coal is roughly estimated using fixed carbon. It is common knowledge that when coal rank rises, the fixed carbon content also rises. According to the outcome, the given coal has high fixed carbon content at 125 micron; this shows the coal quality could be high in this particle size. The moisture content, volatile matter and ash content have high percentage value at 500micron particle size.

Table 4. Proximate analysis result of coal

Size in µm	moisture %	volatile matter%	Ash (%)	Fixed carbon (%)
500	21.02	31.13	16.10	38.02
250	16.75	25	16.08	63.65
125	16	23.8	16.01	79.47
63	15	22.5	15	35
Average	17.19	25.6	19.87	54

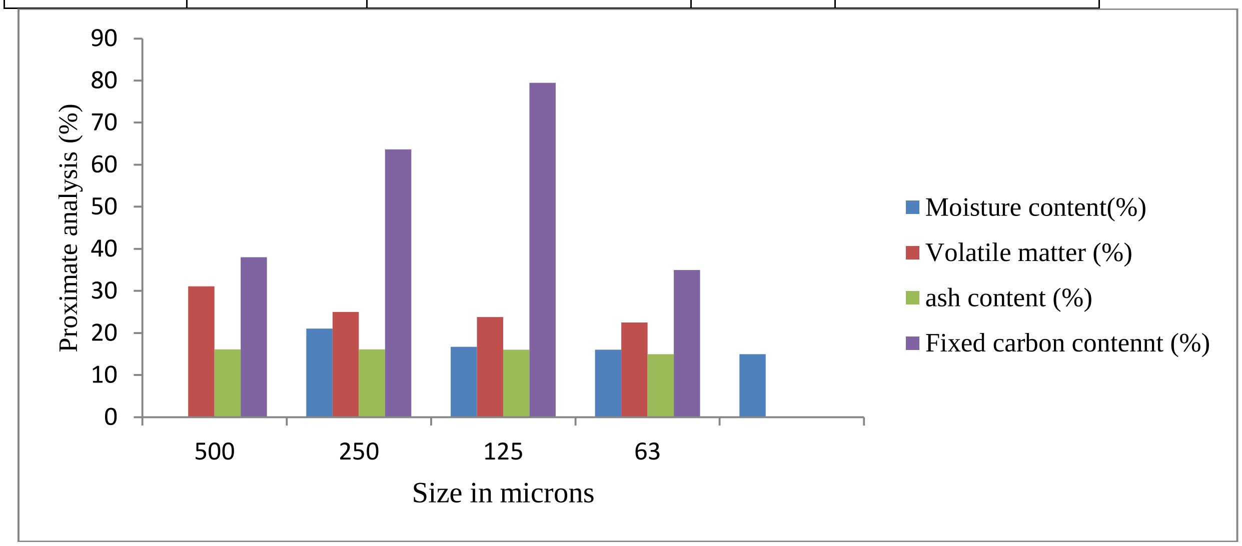

Figure 17. Proximate analysis result of coal

The above figure 17 shows the highest fixed carbon content have obtained at 125 and 250 micron particle size. Compared with the two each other, 125micron was higher; this shows the coal sample could be floated in the good manner at 125 micron.

4.5. Ultimate Analysis

The percentage mass fraction of coal's main ingredients, such as nitrogen, carbon, hydrogen, sulfur and oxygen, is determined by ultimate analysis. It was used to do calculations related to combustion, including figuring out how much air was needed for burning, sulfur emissions and the makeup of the combustion gases.

Table 5. Yayo coal ultimate analysis value (%)

Stream	Carbon (%)	Hydrogen (%)	Oxygen (%)	Sulfur (%)
Washed coal	62.022	4.558	27.1653	12.87

Tailing	6.077	10.18	53.33	1.86

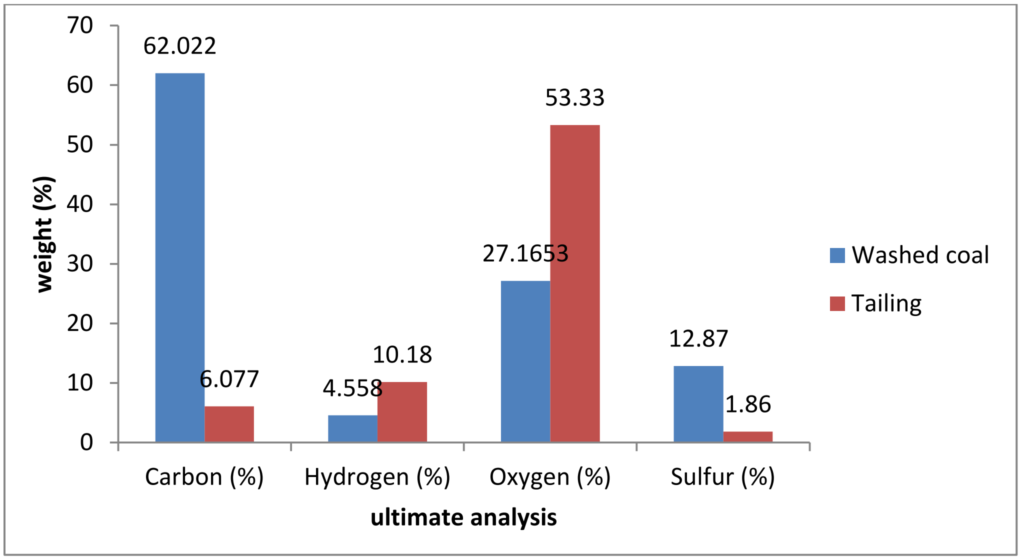

Figure 18. Yayo coal sample's average ultimate value

Figure 18 depicts the average ultimate value of Yayo coal. Based on this value, the quantity of sulfur in this coal is relatively low; the clean coal highest carbon content compared to the others ultimate analysis values, which were hydrogen, oxygen and sulfur. The weight percentage increase the quality of the coal also increase.

Chapter Five

5.1. Conclusion

The coal in this project was finely cleaned due to a problem with coal washing in the pertinent waste disposal. The carbon, nitrogen, oxygen, sulphur and hydrogen contents of Yayo coals in south-western Ethiopia were determined and compared using physicochemical and thermal characterisation. Proximate and ultimate analyses were done for four sample sizes taken from the Yayo coal area in southwest Ethiopia. The coal samples had substantial carbon content and relatively low sulphur and ash percentages, according to the final analysis. Using proximate analysis, the study's simulated coal samples showed that the deposits' coal had moisture contents ranging from 16.5% to 21.2%, volatile matter values between 19.5% and 22.3% and ash ranges between 6.42 to 89.3%. The average values of the ultimate analysis of coal were 62.022% carbon, 4.558% hydrogen, 27.1653% oxygen and 12.87% sulphur were obtained from the coal's final analysis.

The findings was showed that the amounts of sulphur, nitrogen and oxygen were significant, which increased the impurity of coal and decreased its quality. It was anticipated that the coals would produce some harmful pollutants when burned due to their high volatile content. METSIM automatically estimated the required amount when the screen size was adjusted to 500 µm, 250 µm or 125 µm. The clean coal concentration falls with a reduction in screen size below 125 µm, but the clean coal product increases with a reduction in screen size from 500 µm to 125 µm. METSIM was able to dynamically simulate the coal mining processes from the ground up to the concentrate and tailings facilities, from the start of construction through closure. The size analysis of Yayo coal sieve testing consisted changing sieves with screen sizes of 500 µm, 250 µm and 125 µm, which produced cleaned coal products with yields of 59.51%, 63.65% and 79.47% respectively. The flow sheet was designed using the METSIM modeling program. Due to the considerable volume of coarse coal particles, the conventional sieves with screen diameters of 500 µm and 250 µm were eliminated for cleaned coal concentrate. Accordingly the result obtained indicated that the study area coal samples are upgraded with relatively better carbon content with low ash content. The percentage yield obtained at the liberation size 125 micron is 35.15% this shows the highest product is obtained. The coal grade in the study area obtained bituminous coal type, because the carbon content shows 79.47%.

5.2. Recommendation

Using the METSIM simulation software, researchers can learn more about the impurity and the program's effectiveness when researching coal beneficiation with froth flotation.

- To analyze the sample based on particle size and develop the flotation flow sheet that produces the percentage of coal impurities and cleaned product after beneficiation, licensed METSIM simulation software should be required.
- METSEM simulation software is the best one to develop froth flotation process flow sheet. But most of the time it is licensed, so the center must be install and give the latest version for students.

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