ADDIS ABABA INSTITUTE OF TECHNOLOGY

CENTER FOR ETHIO-MINES DEVELOPMENT

DEPARTMENT OF MINERAL ENGINEERING

(GRADUATE PROJECT WORK)

“BENEFICIATION AND UPGRADING OF COAL VIA DENSE MEDIA SEPARATION (DMS) IN ANKOBER WOREDA, NORTH SHEWA ZONE”

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Addis Ababa, Ethiopia

DECLARATION

I, Gizachew Ayu Tarekegn, I declare that this project work is the result of my own work and that all source and material used for this project work have been duly acknowledged. This project is submitted in partial fulfillment of the requirement for master of engineering in Center for Ethio-mines development in department of mineral engineering at Addis Ababa University. I confidently declare that this project has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate.

Name: Gizachew Ayu

Signature:

Date: 29/06/2023

APPROVAL SHEET

This Project paper entitled **"**BENEFICIATION AND UPGRADING OF COAL VIA DENSE MEDIA SEPARATION (DMS) IN ANKOBER WOREDA, NORTH SHEWA ZONE" prepared and submitted by **Gizachew Ayu** in partial fulfillment of the requirements for the subject project work for Master of Engineering in the University of Addis Ababa; Center for Ethio-mines development in department of mineral engineering has been examined and is hereby recommended for acceptance and approval for final oral defense.

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ABSTRACT

Coal is a type of fossil fuel and a combustible black or brownish-black sedimentary rock, formed when dead plant matter decays into peat and is converted into coal by the heat and pressure of deep burial over millions of years as rock strata and used as a fuel for energy resource. But, coal is usually formed associated with gang mineral (ash) those can decrease combustibility of coal. Thus, to utilize this resource safely and efficiently, coal separation and concentration is required. Density-based rejection of ash is an effective method to remove gangue before the process of coal combustion for the purpose of improving the quality of coal. By using a uniform crushed particle size of coal sample (-4.75+4.5 mm) in different specific gravities of heavy medium (1.4, 1.6, and 1.6), the specific gravity of 1.4 was found to be the optimum parameters to successfully upgrade the coal and improve its calorific value. Based on the results of the float product of 32.8% of concentrated coal and 24% upgraded coal obtained with reduced ash content of 60.72% and 21.79% increase of fixed carbon at specific gravity 1.4 and also it was found that upgrading, floating, fixed carbon as well as ash reduction subsequently decreases in floats as the specific gravity increases unlike volatile matter. From this work, it can be concluded that beneficiation and upgrading of coal by dense media separation method is good technique to produce improved and safely used coal as an energy source for coal-fired utilization.

Key words

Coal, sink-float, DMS, specific gravity, ash reduction, proximate analysis, grade, recovery

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1. INTRODUCTION

1.1 Back Ground

Because of coal is made primarily of the element carbon and contains varying proportions of the other elements, coal is categorized as an organic material. Due to the variability of organic matter and the presence of marsh and swamp forms, each coal deposit can have a wide range of physical and chemical properties. Electricity is typically produced using coal as a fuel (source of energy). In coal-fired power plants, coals (including lignite, subbituminous, bituminous, and anthracite) are burned to provide heat. Additionally, it is used to turn water into steam at high pressure, which powers a turbine and generates energy (Meyer, 2010).

According to the statistical evaluation of the world energy complete report, coal is the principal energy source and makes up approximately 27% of the total energy resource. It also has a significant impact on the global economic development. However, hazardous substances are frequently present in raw coal during the coal combustion process. It is common knowledge that the release of hazardous trace metals from burning coal has a negative impact on both human health and the environment. In general, gangue has a substantially higher density than coal. Therefore, removing gangue before to coal burning is a useful way to improve coal quality and lower dangerous element emissions.

1.2. Statement of problem

The reason this work is required because coal is the primary energy source and accounts big share of total energy resource. But in Ethiopia, due to unavailability of technologies and also lack of coal processing plants by dense media separation, upgrading the low grade coal and use it important energy resource is not adopted and unpractical. So to upgrade North Shewa Zone Ankober Woreda's coal, density based separation has to be performed and use it in share of total energy resource for our economic development.

1.3 Objective of the project

1.3.1 Main objective

The main objective of this work is so as to study upgrading of low grade coal by dense media separation (DMS) method which is obtained from Ankober Woreda in North Shewa Zone.

1.3.2 Specific objectives

- Regulate optimum working particle sizes of the coal sample and specific gravities of dense media separation solution.
- Conduct experimental analysis of coal using dense media separation (coal DMS test) and
- Characterize the proximate analysis and calorific value of raw coal before treatment and after treatment.

1.4. Scope of the project

The range of this project is more focused on sampling, processing and concentration of coal so as to upgrade or decrease its ash content by using density based separation technique (DMS) and proximate analysis of the concentrated coal samples which is found in the area of Ankober Woreda, North Shewa Zone in Central Ethiopia.

1.5. Location and accessibility

The coal project area is located in Washa kebele, Ankober Woreda, North Shewa Zone in Central Ethiopia. The bounding geographic coordinates of the corner points of the area are captured by hand held GPS, using ADINDAN coordinate system, Datum D Adindan, UTM Zone 37. The project area is accessed through Debre Birhan to Ankober 42 km asphalt road and from Ankober to Washa about 15 Km and also towards the coal site is all weathered gravel road.

Table 1: Geographic coordinates of coal project area

Corners Points	Easting	Northing
1	589775.00	1051120.00
2	589775.00	1051480.00
3	589220.00	1051480.00
4	589220.00	1051120.00

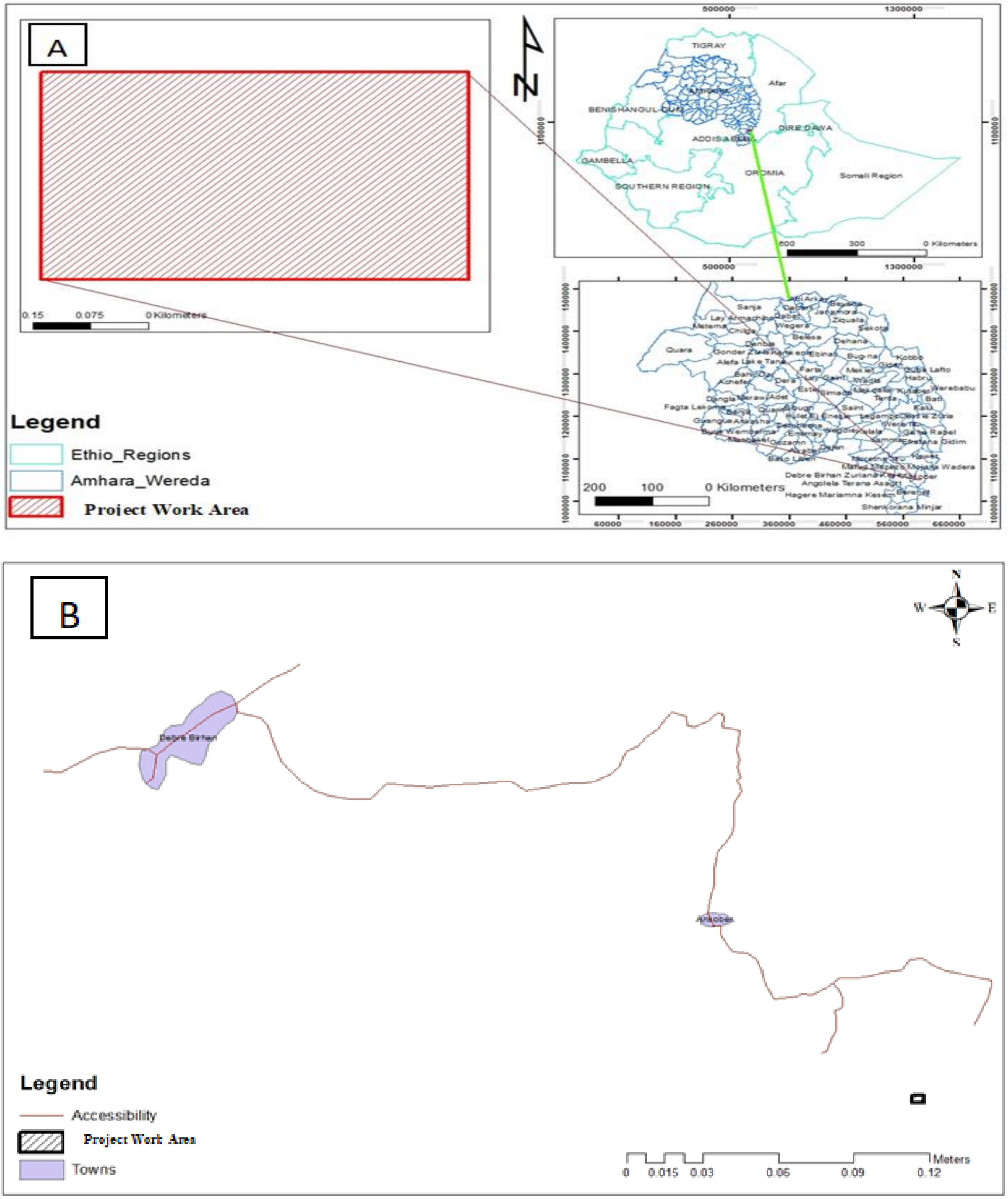


Figure 1: Location (A) and accessibility (B) layout map of the coal project work Area

1.6 Significance of the project work

The significance of this project is concentration of coal by heavy media separation methods and it will provide important information for this coal future processing plant. It will also be used as a reference and indicator to conduct for further researches for the purpose of beneficiation of coal in the area.

1.7 Limitations

- ✓ Unavailability and lack of processing laboratory analytical materials/instruments and (DMS) Chemicals,
- ✓ Shortage of time for project tasks accomplishment and
- ✓ Limitation of budget.

2. LITERATURE REVIEW

2.1 Formation and chemistry of coal

Carbonaceous material, which accumulates and decomposes plant matter in marshes, freshwater habitats, and other ecosystems, is the main component of coal. Coalification is the procedure caused by humified plant materials to become consolidated into coal as it accumulates (Jody K. Tishmack & Perre E. Burns , 2004).

2.2 The Ethiopian coal

Ethiopian coal deposits are divided into Pre-Trap volcanic and Inter-Trappean volcanic geological settings. In Ethiopia, there are two different kinds of sedimentary successions that include coal. These consist of the siltstone/mudstone-coal-shale facies and the sandstone-coal-shale facies, respectively. There are significant reserves of coal. The country's coal reserves can be utilized as an alternative form of energy (Wolela, 2007).

2.3 Beneficiation of coal

The gangue, which contains different minerals including pyrite and quartz and is much denser than coal, is frequently where harmful components concentrate. Thus, removing gangue prior to coal combustion can be accomplished effectively via density-based rejection. In general, wet or dry processing techniques need to be used to remove ash-forming inorganic debris from low grade run-of-mine (ROM) coal.

2.3.1 Wet mechanical separation processes

The wet beneficiation techniques are well adopted all over the world because they achieve a quality product with high recovery. The wet beneficiation processes such as heavy media separation that is relevant to different size fractions of coal are practiced throughout the world (Çetinkaya & Bayat, 2019).

The heavy media separation process is based on the specific gravity difference between coal and the associated extraneous mineral matter. Zinc chloride ($ZnCl_4$) solutions of various specific gravities at $25^{o}C$ are used as dense medium liquids (Zeki Aktas, Filiz Karacan, Aral Olcay, 1988).

2.3.2 Dry mechanical separation processes

Dry separation technologies can separate coal and gangue due to the differences in physical characteristics, such as density and particle size. Technologies for dry gravity separation mostly use the difference in densities to separate coal and gangue (Chenyang Zhou, Xibu Liu, et al., 2021).

Using the difference in terminal velocities between the coal and the gangue, pneumatic separation technology is employed to remove the gangue. In the meantime, pulsed gas flow introduces vibration energy to boost segregation effectiveness. The density difference between coal and gangue is the basic basis for the separation principle (Chenyang Zhou, Xibu Liu, et al., 2021) and (Boylu, F., Tali E., et al., 2014).

3. MATERIALS AND METHODOLOGY

3.1 Materials

The materials mainly used in the project work for experimental analysis associated with their functions are listed below:

- Handy hammer crusher: - for reduction of top size for suitable feed to jaw crusher.
- Jaw crusher: - for further size reduction to optimum sink-float test of this work.
- Different sieves: - for screening and selection of appropriate coal sample size.
- DMS chemicals: - (zinc chloride and distilled water) for making DMS solutions.
- Beam balance: - for measurements of mass (weight).
- Hydrometer: - for measurements of specific gravity of the DMS solutions.
- Water:- for washing and cleaning
- Oven: - for drying.
- Cylinders: - for measuring the volume of the added water.
- Different testing equipment like beakers, holding plastics and containers.
- Gloves and other safety materials.

3.2 Methodologies

3.2.1 Desk work and data collection

It involves all preparations for the project work including collection of secondary data literatures like published and unpublished reports, journal articles, pervious works and other preliminary researches as well as collection of relevant primary data (physico-chemical) data like DMS chemicals, laboratory sites, processing equipment about the processing and concentration by dense media separation for beneficiation of coal.

3.2.2 Sampling method

The representative coal samples were taken from North Shewa Zone Ankober Woreda's coal deposit. The sampling method was simple random sampling for the purpose of the population sampling free from basis (favor or restriction), needs a minimum knowledge and simple to use for studying the population.

During sampling, different Pitts of variable depth were dug for sampling as appropriate in the selected project work site. Sampling was performed from pits in so as to obtain existence and excellence of the representative coal sample in the deposit. Accordingly, sufficient and representative coal samples were collected for the DMS tests as well as proximate analysis.

3.2.3 Preparation of the sample and DMS solutions for processing

3.2.3.1 Sample Comminution and Quartering

The samples, which reflect the whole coal deposit in the area and were gathered in line with the sampling technique as simple random sampling, were combined and weighed at 15 kg. The coal sample was crushed and sieved to acquire the best particle size for sink-float analysis, yielding a predefined quantity of the representative coal sample.

From the collected gross coal sample (which was weighted 15 kilogram), 12 kilogram coal sample having 100 mm diameter was crushed by first in handy hammer crusher decreased to the size of 25 mm. The crushed coal sample was further reduced into smaller particle size by using jaw crusher. The divided to 1/4th of its weight by using riffle splitter technique each weighing 3 kilogram for the purpose of taking representative from the crushed coal sample.

Figure 2: Shows crushing and quartering of coal sample for next laboratory tests and analysis

Table 2: Crushing and quartering products

Activity	Type	Amount (k.g.)	Particle Size (mm)	Product Size (mm)
Crusher	Handy hammer crusher	12	-100+25	≤25
	Jaw crusher	12	≤25	-6.25+2
Quartering	Q1	3	-6.25+2	-6.25+2
	Q2	3	-6.25+2	
	Q3	3	-6.25+2	
	Q4	3	-6.25+2	

3.2.3.2 Sieving and screening

Prior to performing sink-float tests, a 3 kilogram sample of crushed and quartered coal was sieved in a series of sieves to eliminate both the finest (4.5 mm) and coarsest (>5 mm) particles in order to prevent disruption caused by their adhesion to the ideal coal particles during the testing and cleaning process. A sample that is crushed by jaw crusher and screened by sieving to the average size of -4.75+4.5 mm was selected for next float–sink test.

Table 3: Sieving and screening

Series of Sieves (mm)	Weight of Retained (gm)	Average Particle Size (mm)	Screening
5.0	332	>5	Screened/rejected
4.5	2000	-5.0+4.5	Selected optimum test size for this work
4.0	394	-4.5+4.0	Screened/rejected
3.5	123	-4.0+3.5	
3.0	58	-3.5+3.0	
2.5	44	-3.0+2.5	
2.0	27	-2.5+2.0	
Pan	22	<2	

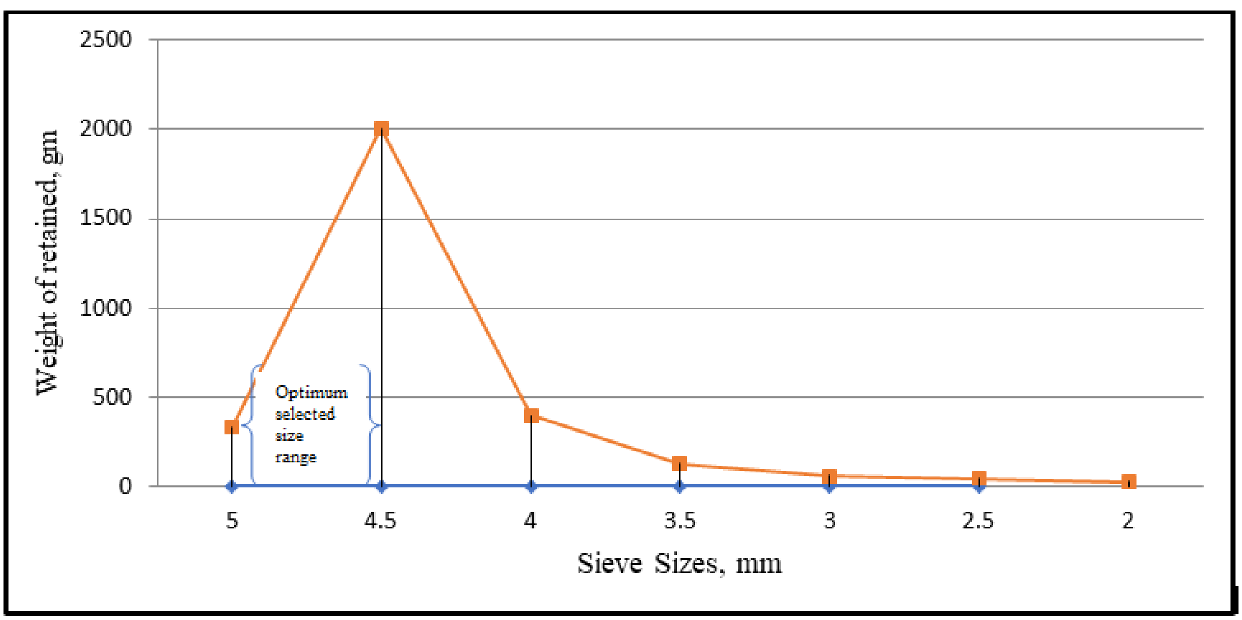


Figure 3: Shows Sieve analysis graph for screening and selecting to obtain predetermined optimum size for sink-float tests

3.2.3.3 Preparation of DMS solutions

With the aid of a calibrated hydrometer, sufficient zinc chloride ($ZnCl_2$) powder and distilled water were employed to create three heavy media solutions with specific gravities of 1.4, 1.6, and 1.8. The float-sink test of an inorganic zinc chloride ($ZnCl_2$) with distilled water together to a volume of 500 ml solution was prepared using beakers, cylinders and stirrer.

Table 4: DMS solution for coal sink-float test preparation

DMS solutions (Beakers)	Specific Gravity (Hydrometer reading)	$ZnCl_2$ powder (gm)	Volume the DMS solution (ml)
B1	1.4	685	500
B2	1.6	782.86	500
B3	1.8	880.72	500

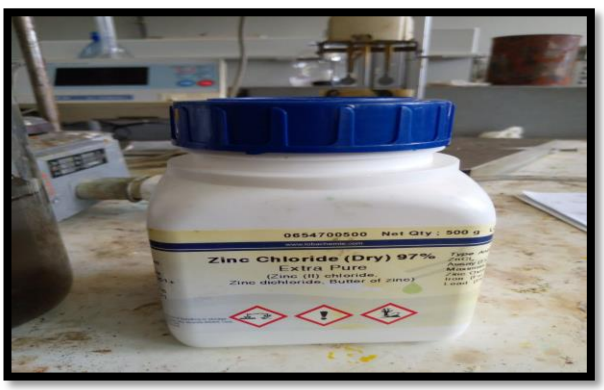


Figure 4: Shows Preparation of DMS solutions for sink-float tests

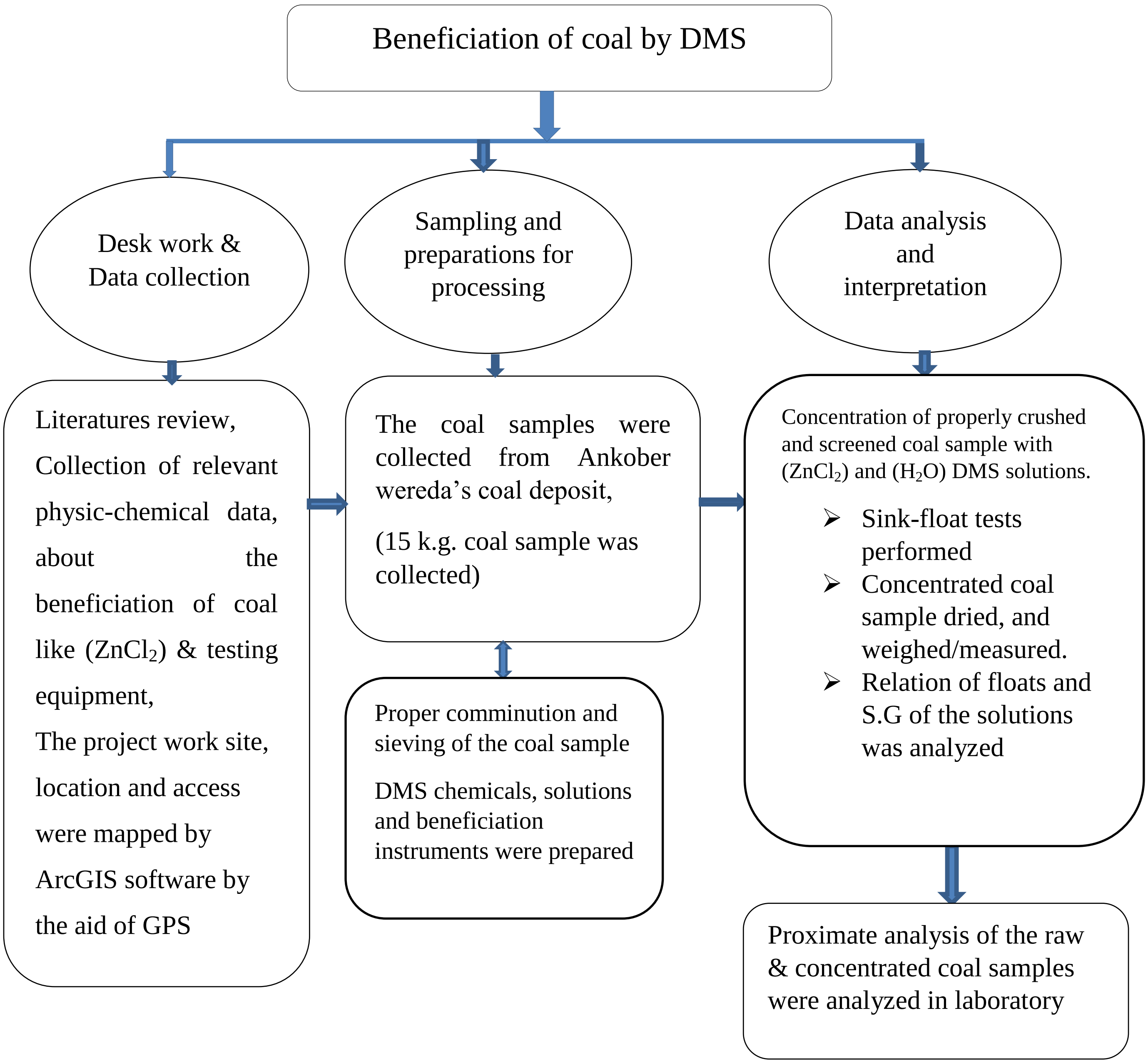


Figure 5: Shows generalized frame work of the study

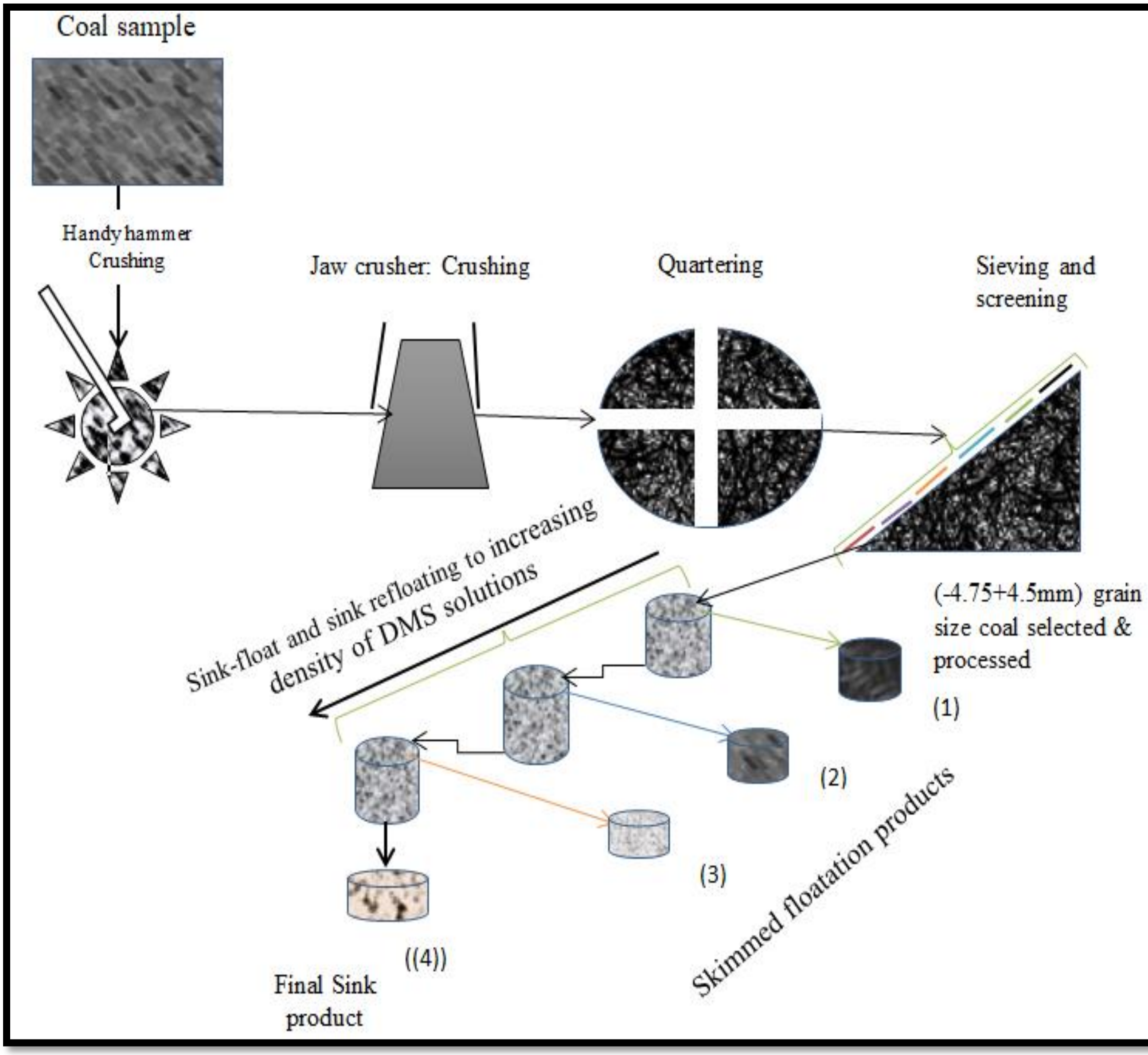
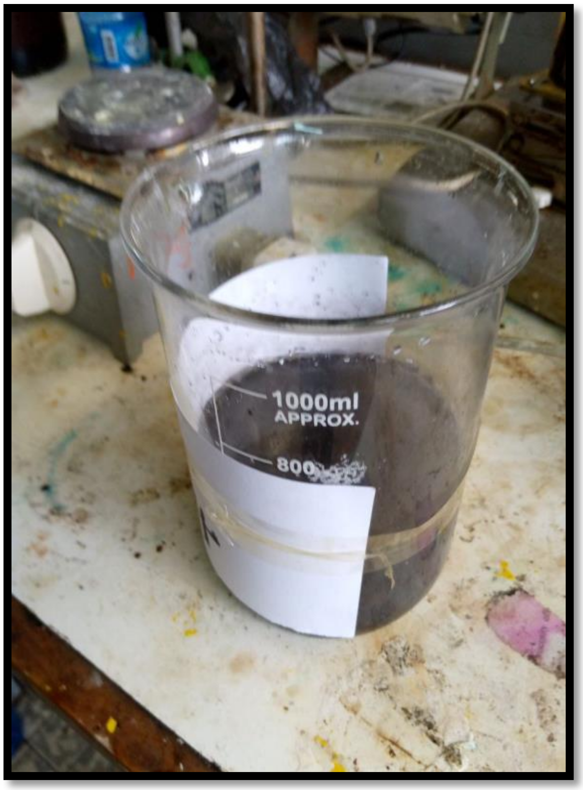


Figure 6: Shows flow diagram of coal sink-float tests by dense media separation

4. RESULT AND DISCUSSIONS

The first set of float-sink tests involved adding a coal sample with a size of 4.75+4.5 mm and a weight of 1 kg gradually and step-by-step into a 500 ml beaker with adequate ZnCl2 solution with a specific gravity of 1.4. The coal sample had been stirred for 5 minutes in order to give the float and sink products and enough time was given for better separation. The first float product, clean coal, was collected, and the sink product with this specific gravity was floated once again with a $ZnCl_2$ solution that had a comparatively higher specific gravity. In a similar manner, its float was gathered, and the sink was moved to a beaker with a higher specific gravity (i.e. 1.6). Until the specific gravity reached 1.8, the same process was repeated. One sink product and three float products with a size fraction of -4.75+4.5 mm were obtained for this set of float-sink. The amounts of material floating were skimmed from the top of the test container regularly.


1000ml
APPROX.
800


1000ml
APPROX.
800
600
400
200
G.G.17


illed H2O

Figure 7: Shows sink-float tests of sample coal in different specific gravity of Zinc chloride DMS solutions.

Table 5: The sink-float tests floatation yields

Tests	DMS Solution Specific Gravities	Feed (gm)	Floats (gm)	Sink (gm)
T1F1	1.4	1000	327	672.5
T1F0	1.6	672.5	223	449.5
T1F2	1.8	449.5	198	250.3
T2F1	1.4	1000	329	670.64
T2F0	1.6	670.64	221	449.03
T2F2	1.8	449.03	195.82	253.01
Average of the two respective equivalent tests	1.4		328	
	1.6		222	
	1.8		196.91	

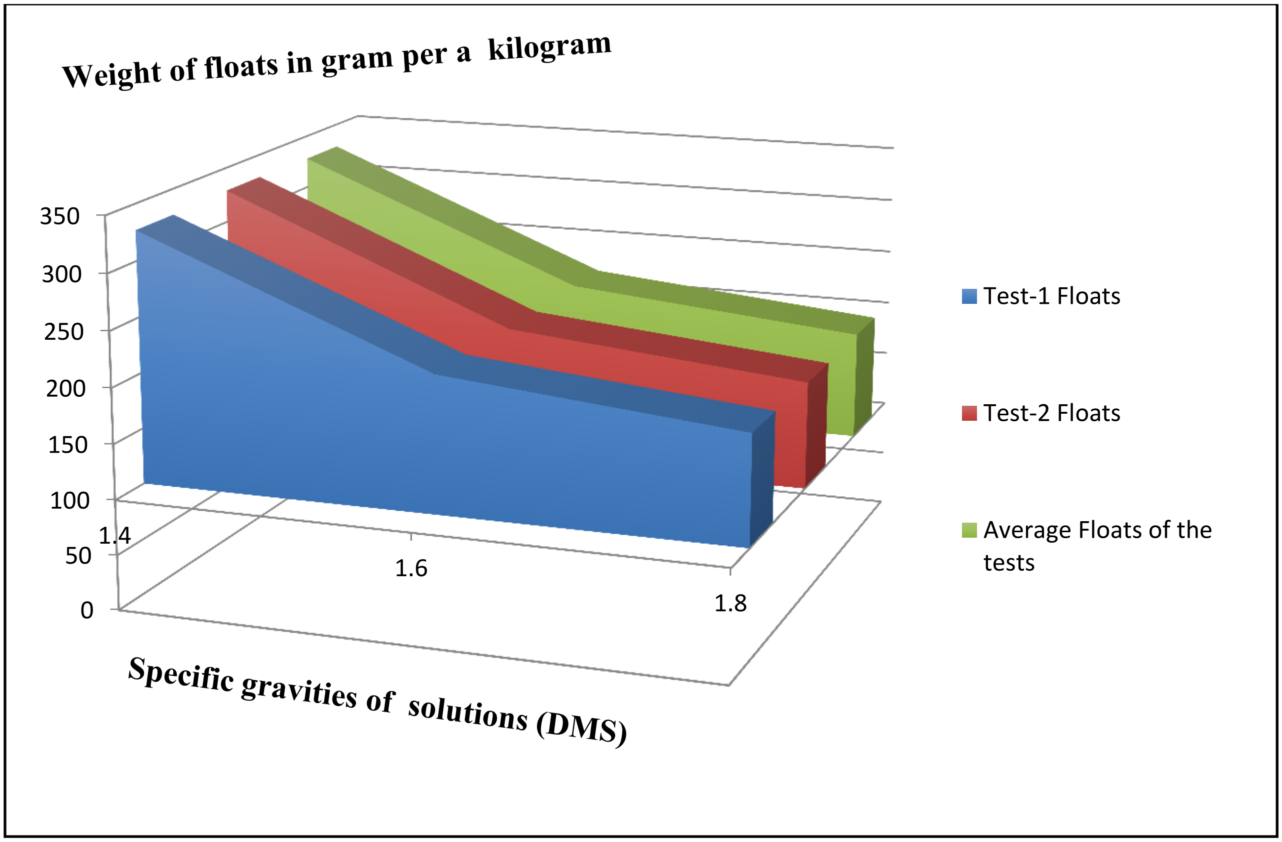


Figure 8: Shows Percent return of float amount from coal samples of same magnitudes (-4.75+4.5 mm) and weight (1 k.g.) at different specific gravities

The retrieval of floated coal samples and grade improvement (upgrading) values were computed following the filtering, drying in an oven at 80C, weighing, and laboratory analysis of the float and sink percentages.

Since, the specific gravity of 1.4 DMS solution was the suitable parameter because of coal has relative density of 1.2–1.5 g/cm^3 to get the concentrated and successfully floated coal.

In test one:

$R_1 = \frac{327gm}{1000gm} * 100\%$ = 32.7% at S.G.; 1.4 and

In test two:

$R_2 = \frac{329gm}{1000gm} * 100\%$ = 32.9% at S.G.; 1.4.

The average fractional recovery value of the concentrated (floated) coal at specific gravity; 1.4 is:

$$R_{av} = \frac{(32.7+32.9)\%}{2} * 100 = \underline{\underline{32.8\%}}.$$

Table 6: The raw and sink-float concentrated coal's proximate and calorific values result

Sample code	**Moisture %**	**Volatile Matter %**	**Fixed Carbon%**	**Ash %**	**Calorific value Cal/gm**	**Sulfur %**	**Specific gravity of DMS Solutions**
T12F1	7.47	31.46	21.79	39.28	3153.15	0.12	1.4
T12F0	12.64	27.28	17.31	42.77	2747.71	0.23	1.6
T12F2	10.12	19.77	0.65	69.46	529	0.02	1.8
T12F3	9.16	18.12	0.60	72.12	408.42	0.02	Sink coal
RCS	14.16	24.26	10.07	51.51	1638.69	0.08	Raw coal

According to the geological survey of Ethiopia's proximate and calorific value laboratory analysis report, proximate and calorific value the raw coal sample laboratory analysis result indicates that the coal is low grade and less quality due to great ash content and little calorific value. The floated coal samples especially at specific gravity 1.4 of the DMS solution becomes improved and upgraded and the last sink coal becomes degraded compared to the raw coal.

The relation of ash, fixed carbon, volatile matter, calorific values of the concentrated coal samples and specific gravity of the testing DMS solution analysis results have been interpreted by applying techniques with the help of excel as follows.

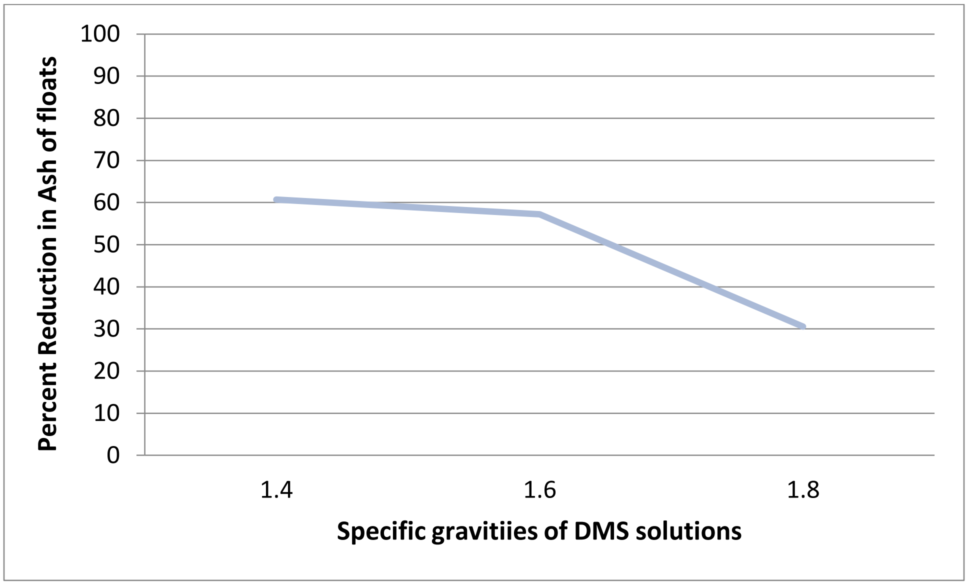


Figure 9: percent reduction in ash from coal samples of equal size but varied specific gravities

The grade improvement of the concentrate floats of coal:

Grade $= 1 - \frac{ac}{af}$, Where, the original feed coal's ash content is represented by the letters ac and af, respectively.

Grade $= 1 - \frac{39.28\,\%}{51.51\%}$ = 1-0.76 = $\underline{\underline{0.24}}$ at specific gravity 1.4.

The result indicates that there is 24% improvement of the concentrated or floated of coal at S.G.; 1.4.compared to the raw coal. This 24% upgraded coal is resulted from reduction of ash (reducing ash of raw coal from 51.515 to 39.28%) due beneficiation of the raw coal by dense media separation (DMS) method.

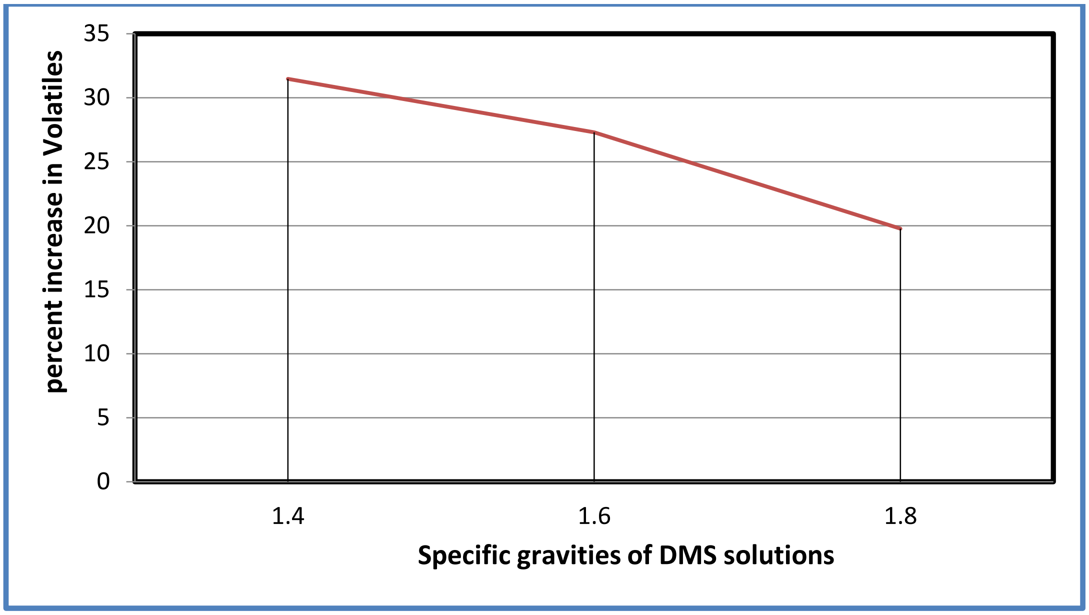


Figure 10: Volatile matter content increased by a certain percentage in coal samples of the same size but with varying specific gravities.

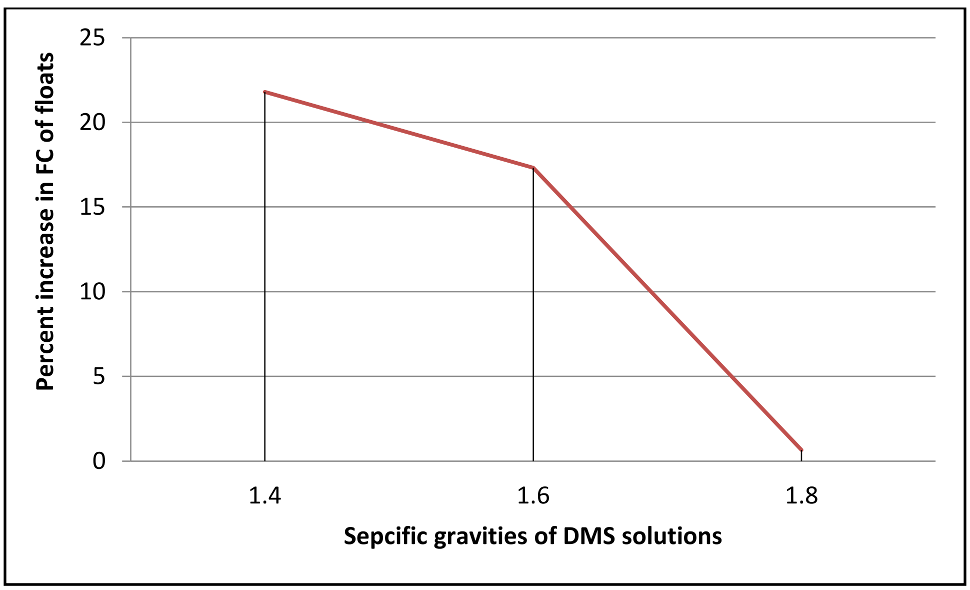


Figure 11: Increase in fixed carbon by percentage in coal samples of the same size and various specific gravities' float products

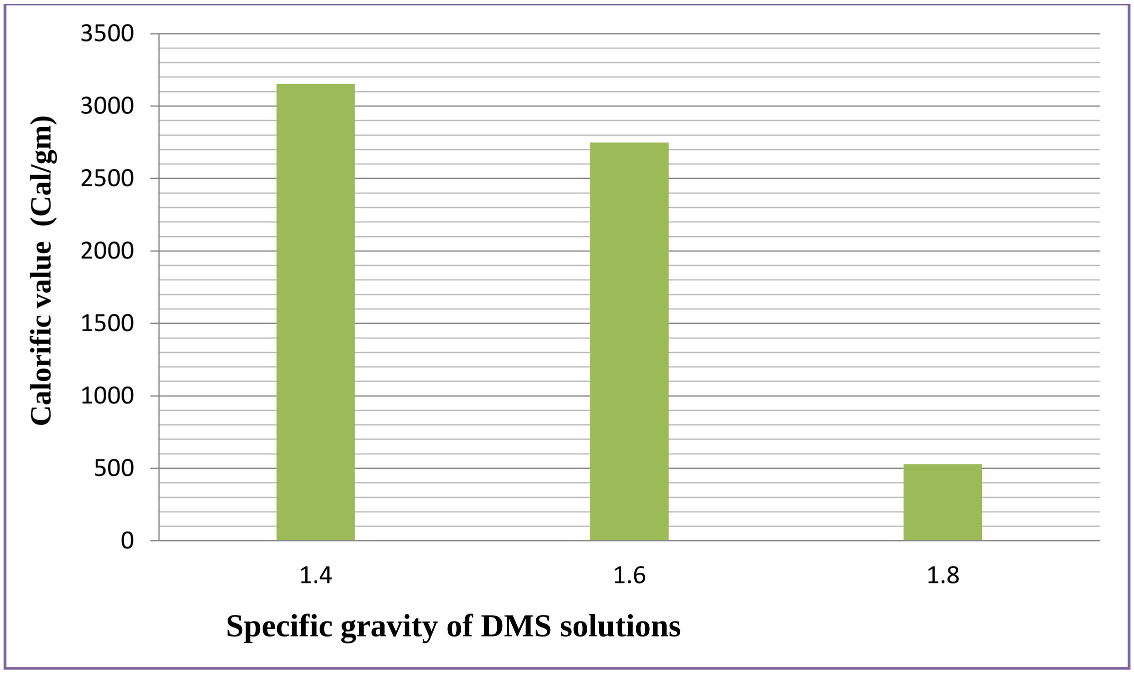


Figure 12: Increase in calorific value by a percentage in float products made from coal samples of various diameters and specific gravities.

As the proximate analysis of the raw coal along with the concentrated coal samples result (figure 9 & table 6) indicates that, 24% improvement of the concentrated (floated) coal at S.G.; 1.4. is obtained compared to the raw coal. The 24% upgraded coal is resulted from reduction of ash due beneficiation of the raw coal by dense media separation (DMS) method.

The last figure (Figure 12) shows improved calorific values (CV) have been obtained mainly in the specific gravity of 1.4 and 1.6. But, in the last refloated and sink coal samples this calorific value becomes decreased due to separation of clean coal in the first and second floatation tests and also due to ash increments as the specific gravity of DMS solution increase.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The Ankober Woreda North Shewa Zone's poor grade coal was upgraded and beneficiated using the heavy media separation technology. A homogeneous coal particle size and various specific gravities of heavy medium were used in experimental sink-float tests to upgrade the coal. By using a uniform crushed particle size of coal sample (-4.75+4.5 mm) in different specific gravities of heavy medium (1.4, 1.6, and 1.6) sink-float concentration, better improvement of coal obtained in related to reduced ash, increased calorific value and fixed carbon. Concentration of low grade coal in DMS is effective method to successfully upgrade the coal and specific gravity of 1.4 DMS zinc chloride solution is found to be the optimum parameter to get upgraded coal.

Based on the results of the float product with the highest yield of 32.8% of concentrated coal and 24% of upgraded coal obtained similarly to the float containing the highest ash reduction of 60.72% with a 21.79% increase in fixed carbon at specific gravity 1.4, it was also discovered that upgrading, floating, fixed carbon, and ash drop later decrease in floats as the specific gravity of the DMS solution increases, with the exception of a small increase in volatile matter. Dense media separation is an excellent technology for producing improved and securely consumed coal as an energy source for coal-fired benefits such as cement and power plants. Beneficiation and upgrading of coal can be accomplished by this method.

5.2 Recommendations

The beneficiation and upgrading of coal by dense media separation (DMS) method was performed for improvement of the low-grade coal. For improvement of the coal, experimental works have been undertaken using a uniform particle size of coal in different specific gravities of heavy medium and is found improved coal in ash reduction as well as calorific value. Based on this work, it is better utilizing heavy media separation techniques to concentrate and upgrade the low grade coal and use it important effect in share of total energy resources for the economic development.

Unavailability of coal beneficiation technologies and lack of coal processing plants in Ethiopia like dense media separation to upgrade low grade coal to use as fuel resource is not common. So, it is recommended that to upgrade the low grade coal resources, technologies like density based separation (DMS) and related beneficiation techniques have to be expanded to improve and safely used coal in coal-fired utilities.

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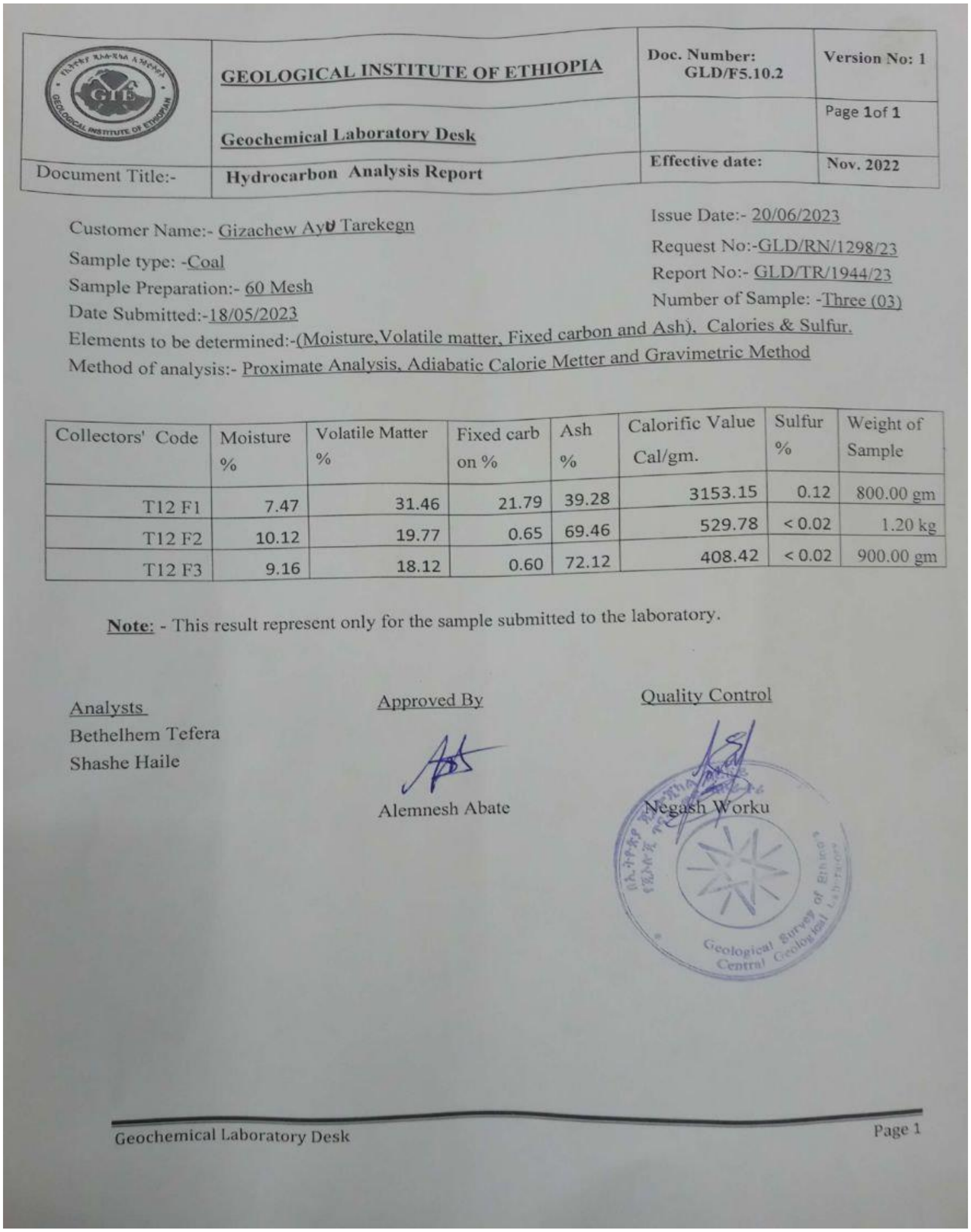
APPENDIX

The figures below shows raw coal as well as the concentrated coal samples proximate and calorific value laboratory analysis result report by Geological survey of Ethiopia and also different captured images during processing and testing.



	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:- Gizachew Ayu Tarekegn

Sample type: -Coal

Sample Preparation:- 60 Mesh

Date Submitted:-18/05/2023

Issue Date:- 20/06/2023

Request No:-GLD/RN/1298/23

Report No:- GLD/TR/1944/23

Number of Sample: -Three (03)

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
T12 F1	7.47	31.46	21.79	39.28	3153.15	0.12	800.00 gm
T12 F2	10.12	19.77	0.65	69.46	529.78	< 0.02	1.20 kg
T12 F3	9.16	18.12	0.60	72.12	408.42	< 0.02	900.00 gm

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

Analysts
Bethelhem Tefera
Shashe Haile

Approved By
Alemnesh Abate

Quality Control
Negash Worku

Geochemical Laboratory Desk — Page 1

	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:- Gizachew Ayu
Issue Date:- 21/06/2023
Sample type: -Coal
Request No:-GLD/RN/1403/23
Sample Preparation:- 60 Mesh
Report No:- GLD/TR/1961/23
Date Submitted:-15/06/2023
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
T12Fo	12.64	27.28	17.31	42.77	2747.71	0.23	1 kg
RCS	14.16	24.26	10.07	51.51	1638.69	0.08	1.3 kg

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

Analysts
Bethelhem Tefera
Shashe Haile

Approved By
Alemnesh Abate

Quality Control
Negash Worku

Geological Survey of Ethiopia Central Geological Laboratory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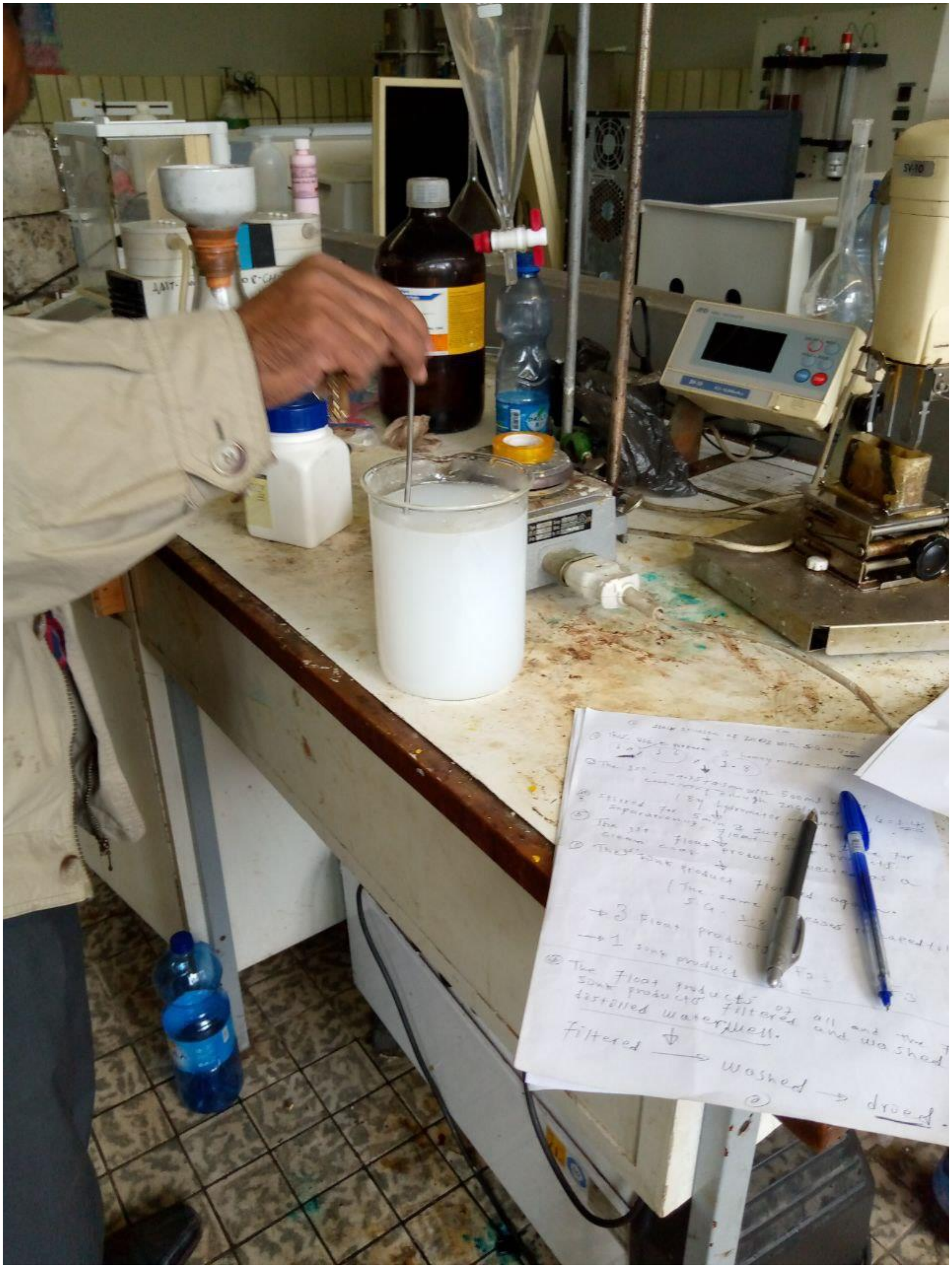
for Authorized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dried


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APPROX.