Proceedings of the 11th World Congress on Mechanical, Chemical, and Material Engineering (MCM'25)
Paris, France - August, 2025
Paper No. MMME 151
DOI: 10.11159/mmme25.151

Impact of Carbonaceous Gangue Removal on the Flotation Performance of a Polymetallic Base Metal Sulphide Ore

Masingita Clinton Mawila[1], Willie Nheta[1], Omoyemi OloladeOla-Omole [2]
[1]Mineral Processing and Technology Research Centre, Department of Metallurgy, University of Johannesburg
Doornfontein Campus, PO Box 17911, Johannesburg, 2028, South Africa
[2]Federal University of Technology, School of Engineering and Engineering Technology, P. M. B 704 Akure, Nigeria
Mawila54@gmail.com; wnheta@uj.ac.za; omoyemiomole@gmail.com

Abstract **-** One of the mines in the Northern Cape of South Africa is currently producing galena and sphalerite concentrates from a polymetallic sulphide ore using differential flotation. Currently, the concentrate grade does not meet the target grade requirements of the Pb and Zn concentrates. The current work investigated the enhancement of the grade and recovery of Pb and Zn by implementing a four-stage flotation process which included a carbonaceous gangue removal first stage. During the gangue flotation stage, Pb and Zn were depressed using $ZnSO_4$ and NaCN. Aero 3418A was used at the Pb flotation stage as a collector while Zn was depressed. At the Zn stage, $CuSO_4$ was used to activate Zn while SIPX was used as a collector and pH was adjusted to 12 with CaO. Taguchi's design of experiments was used to optimize the reagent dosages. The ore samples from the East Pit showed higher Pb and Zn grades of 1.1% and 9.38%, respectively, whilst the samples from the West Pit had Pb and Zn grades of 0.66% and 5.92%. Pyrite was the most crystalised mineral in both samples, according to the XRD data, followed by sphalerite, quartz, and galena. Since 32% C removal was reached in the gangue removing stage in the East Pit and 63.6% in the West Pit, the East Pit proved challenging to treat. The two highest Pb recoveries and grades were 70.9% with an 11% grade (West Pit) and 61.1% with a 16.8% grade (East Pit). The West and East Pit samples yielded recoveries of 92.5% and 89.6% for zinc, respectively.

Keywords**:** Galena, Sphalerite, Polymetallic Sulphide, Pyrite, Depressant, Collectors, Pre-stage Flotation.

1. Introduction

South Africa hosts massive polymetallic base metal sulphide ores found in the Black Mountain, Northern Cape. This ore deposit consists of chalcopyrite, pyrrhotite, pyrite, galena, and sphalerite as the main primary sulphide minerals [1]. A differential froth flotation process is used to concentrate galena and sphalerite from this ore deposit. Galena is concentrated first followed by sphalerite. The main sulphide gangue mineral in the flotation circuits processing galena and sphalerite is pyrite [2]. Reducing the iron (Fe) and zinc (Zn) content of the lead concentrate is essential for the flotation of galena. Additionally, lowering the zinc concentrate's iron content is crucial to improving the process economy. Furthermore, boosting Pb and Zn flotation recovery will lessen the harmful effects that tailings have on the environment. This can be challenging at times since complex ores behave differently from single-mineral ores because of galvanic interactions, dissolved ion activation, collector type and dosage, and other variables [3]. In addition, lead-zinc ores contain carbonaceous material. These carbonaceous materials float easily leading to dilution of grades and high consumption of flotation reagents.

Flotation reagents play a major role in the grade and recovery of base metal sulphides. Many flotation circuits have been optimised in terms of reagent dosages, however, the ore mineralogy keeps on changing from one area to another. This becomes even more complex when processing polymetallic sulphide base metal ores, leading to many circuits not meeting their designed targets. Many researchers have suggested several solutions including spraying the surface froth during flotation), use of novel reagents [4, 5] and even introducing reagents during the milling stage.

The mining industry has recently shown interest in polymetallic sulphide deposits because of their high concentration of base and precious metals. Although the differential lead-zinc flotation process has been in use since 1912, several mining operations still struggle with the process's selectivity [6] . Parameters such as optimization of reagents, depressants, collector dosages and pH were investigated for the flotation process, but still there is need to optimise the flotation process for individual ores. In this study, two complex ore bodies were studied with aim of optimising recovery and grade of galena and sphalerite by removing carbonaceous minerals prior to differential flotation. A four-stage flotation process was used to recover base metals from the polymetallic base metal ores.

2. Materials and Methods

2.1 Materials

The feed samples were sourced from one of the processing Mines located within the Black Mountain Mining complex in the Northern Cape province of South Africa. Kemtec company supplied 96% pure sodium isopropyl xanthate (SIPX) which was used as the Zn collector. Betachem (Pty) Ltd. supplied the hydrofroth used in the Pb and Zn flotation stages, while methyl isobutyl carbinol (MIBC) served as the frother in the gangue flotation stage. Ace supplied the Copper sulphate which was used as the sphalerite activator. The depressants used for sulphides were Sodium cyanide and Zinc sulphate while lime (Calcium Oxide) was used as a pH regulator. Aero 3418A which was used as a collector in the Pb flotation stage was supplied by Cytec, South Africa.

2.2 Methods

The samples collected from the East and West Pits were split separately to prepare 2Kgs aliquots at 100% passing 1.7mm. The samples were milled using a rod mill to create the milling curves with the aim of obtaining 80% passing 75 microns. Zinc Sulphate ($ZnSO_4$) was added to the mill for depressing pyrite. Reverse osmosis (RO) water was used throughout the experiments to make a slurry of 30% solids. The flotation tests were carried out in a 5-litre Denver flotation cell. The speed was kept constant at 1200rpm for the rougher and 900rpm for the cleaner stages using a small impeller at 5L/min airflow rate. Flotation concentrate was manually scrapped after every 15 seconds. Reagent dosage optimization was conducted according to Table 1 below.

A constant dosage of 14g/t MIBC was used as frother and conditioned for 1 minute during the gangue flotation stage to collect the carbonaceous and other natural hydrophilic materials at a natural pH. After 2 minutes, the pH was increased to 10. NaCN varied between 50-100g/t was added and conditioned for 2 minutes to depress the Sphalerite. Aero 3418A collector was added and conditioned for 2 minutes and kept constant at 25g/t. Hydrofroth was also added and conditioned for a minute. The Pb Concentration was collected for 6 minutes. After the Galena float, calcium oxide (CaO) was added to increase the pH to 12, then Copper sulphate ($CuSO_4$) varying from 100-1000g/t and conditioned for 3 minutes to activate the sphalerite. The flotation collector used to collect the sphalerite was Sodium isopropyl xanthate (SIPX) varied between 10-100g/t and conditioned for 2 minutes. Hydrofroth was then added and conditioned for a minute. The concentrate was collected for 12 minutes. The flotation experiments were carried out according to Table 2.

The concentrates and tailings were filtered and dried in the oven at 50 degrees Celsius. The dried samples were analysed at SGS Randfontein Laboratory for base metals, total carbon and sulphur content.

Table 1: Summary of reagents used in the flotation experiments.

Reagents	Function	Reagent dosage	Conditioning time
1. SIPX	Collector	50-100g/t	5
2. Aero 3418A	Collector	10-50g/t	3
3. Copper sulfate	Activator	100-800g/t	5
4. NaCN	Depressant	50-100g/t	2
5. ZnSO4	Depressant	100-500g/t	2
6. MIBC	Frother	10-50g/t	1
7. Hydrofroth	Frother	10-50	1

Table 2: Summary of the reagent suite used for the flotation experiments.

Test No	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10

ZnSO4	300g/t	250g/t	200g/t	150g/t	100g/t	300g/t	300g/t	300g/t	300g/t	300g/t
NaCN	100g/t	100g/t	100g/t	100g/t	100g/t	100g/t	100g/t	100g/t	100g/t	100g/t
MIBC	14g/t	14g/t	14g/t	14g/t	14g/t	14g/t	14g/t	14g/t	14g/t	14g/t
Aero 3418A	25g/t	25g/t	25g/t	25g/t	25g/t	25g/t	25g/t	25g/t	25g/t	25g/t
HydroFroth	As required	As required	As required	As required	As required	As required	As required	As required	As required	As required
CuSO4	800g/t	800g/t	800g/t	800g/t	800g/t	400g/t	500g/t	600g/t	800g/t	800g/t
SIPX	80g/t	80g/t	80g/t	80g/t	80g/t	80g/t	80g/t	80g/t	50g/t	65g/t
Hydrofroth	As required	As required	As required	As required	As required	As required	As required	As required	As required	As required

3. Results and discussion

3.1 Chemical Composition of the Polymetallic sulphide ore samples

The elemental composition of the samples obtained from the East and West pits was analysed using X-ray fluorescence (XRF) and the results are shown in Tables 2 and 3. The West pit sample had a lower grades Zn and Pb of 5.92 and 0.66% respectively. West Pit sample had higher Zn and Pb grades at 6.38% and 1.1% respectively. The West Pit had a lower Fe grade of 20.99% compared to the East Pit sample with 24.38%. The Total Carbon of the East Pit sample was higher (0.69% C) than the West Pit sample (0.49% C). Precious metals were so low in both samples, and they were not tracked during the flotation test work.

Table 2: Chemical analysis results of the East Pit Sample

East Pit	Co	Cr	Cu	Fe	Mn	Pb	Zn	C	S	Al	Ca	Other
Description	%	%	%	%	%	%	%	%	%	%	%	%
Head Grade	0.01	0.47	0.05	24.38	0.6	1.1	6.38	0.69	27.26	5.21	0.22	30.69

Table 3:Chemical analysis results of the West Pit Sample

West Pit	Co	Cr	Cu	Fe	Mn	Pb	Zn	C	S	Al	Ca	Other
Description	%	%	%	%	%	%	%	%	%	%	%	%
Head Grade	0.01	0.95	0.04	20.99	0.74	0.66	5.92	0.49	19.30	4.33	0.45	46.12

3.2 Mineralogical Phases of the Polymetallic sulphide ore

Fig.1 below shows the X-ray diffraction (XRD) results of the East pit sample. The major valuable mineral phases found in the sample were sphalerite, and galena associated with pyrite, quartz, bauxite and calcite as gangue minerals. This mineralogy is typical of the Black Mountain ore [7].

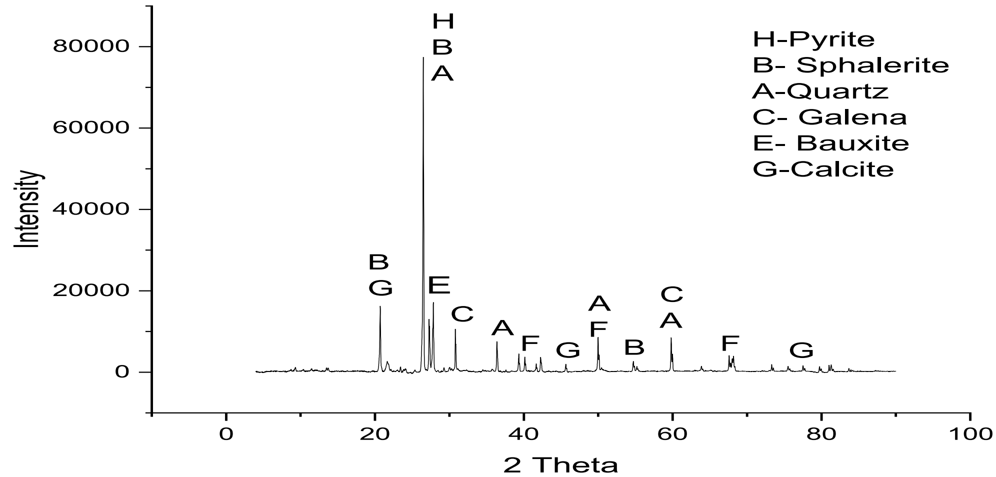

Fig 1: XRD spectra of the East pit ore sample.

3.3 Bulk mineral composition of East and West ore samples

Table 4 below shows the dominant minerals in the Bulk Composition (BC) of the ore samples. MnFe_Sphalerite was dominant with 86.46% in the West Pit sample and 84.28% in the East Pit sample. Fe_ Sphalerite followed with East Pit sample higher than the West Pit with 13.16% and 10.97% respectively. Pyrite was the least in both samples with East Pit at 0.11% and West Pit at 0.19%. Compared to the East Pit sample (0.89%), Galena was more prevalent in the West Pit sample (0.97%). In addition, the West Pit had a higher percentage of sphalerite (1.24%) than the East Pit (1.20%).

Table 4:Bulk mineral composition of East and West ore samples

Bulk Modal / Sample	**West Pit Sample (% wt)**	**East Pit Sample (% wt)**
MnFe_Sphalerite	86.46	84.28
Fe_Sphalerite	10.97	13.16
Sphalerite	1.24	1.20
Galena	0.97	0.89
*Others	0.25	0.31
Pyrite	0.11	0.19
Total	**100.00**	**100.00**

3.4 Surface Morphology Analysis of the East Pit Sample

Scanning electron microscopy (SEM) was used to determine the surface morphology of minerals present in the East pit sample and the results are presented in Fig. 2. The results confirmed the results found using XRD. Dominant minerals are pyrite, sphalerite, galena and quartz.

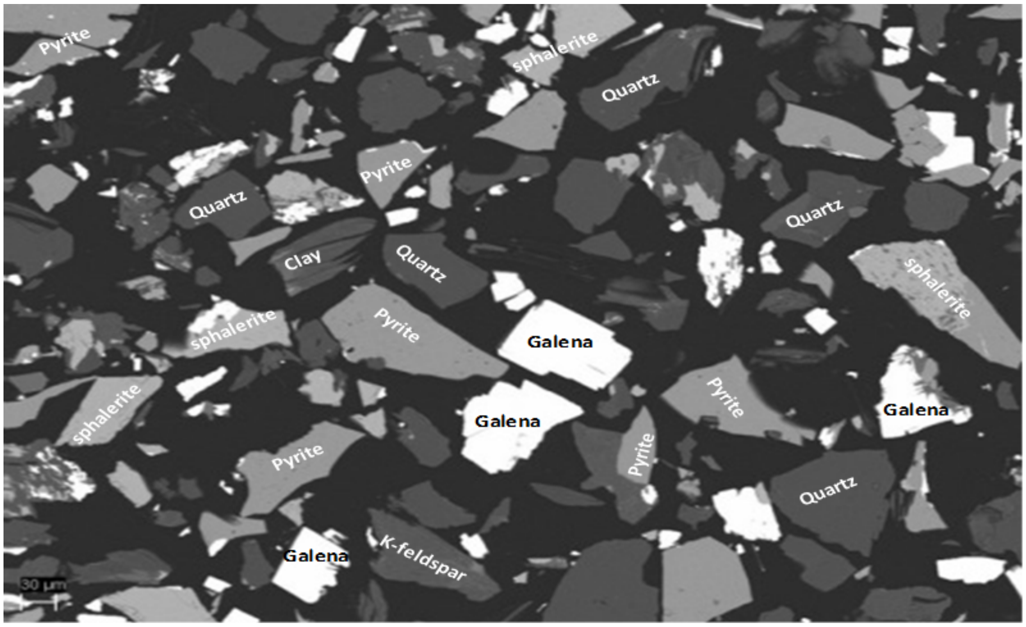

Fig. 2: SEM-EDS images of the East pit ore sample

3.5. Results of the bench flotation tests

3.5.1 Carbonaceous gangue flotation stage results

The impact of depressant, collector and frother dosages on the carbonaceous material recovery was investigated and the results are shown in Fig. 3 and 4. The results show that Test 4 in both samples under conditions: 150g/t $ZnSO_4$, 100g/t NaCN and 14g/t MIBC, West Pit had a higher carbonaceous material recovery during the gangue flotation stage with a gangue recovery of 63.6% at a grade of 32% than the East Pit with 32.9% recovery and a grade of 12.3%.

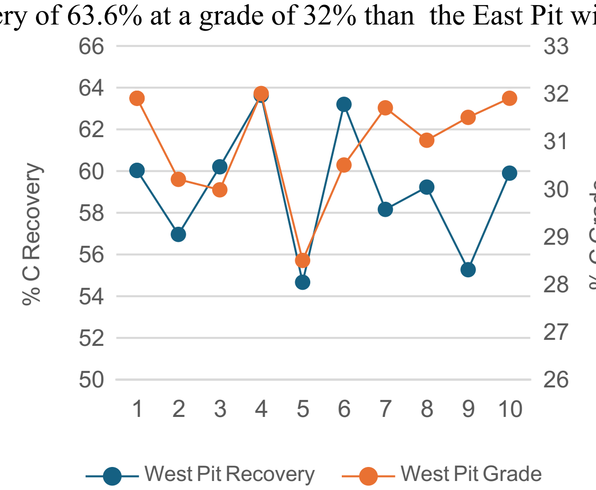

Fig 3: West Pit carbonaceous gangue flotation stage

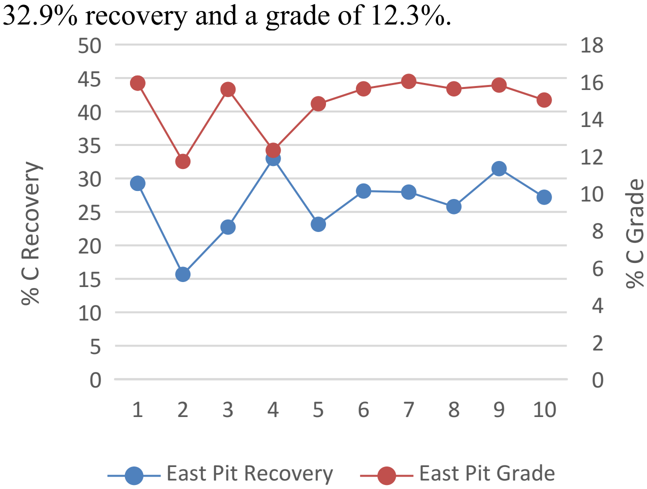

Fig 4: East Pit carbonaceous gangue flotation stage

3.5.2 Pb rougher flotation stage results

The Pb flotation results shown in Fig. 5 and 6 revealed that West Pit had the highest Pb recovery of 70.9% with a grade of 11% followed by test 4 and test 3 with similar Pb recoveries of 68.8 and 68.9% respectively. East Pit was difficult to treat as poor Pb recovery of 61.1% with a grade of 16.8% was highest recovery achieved. The conditions of 250g/t $ZnSO_4$ and 100g/t NaCN were used under Test 2 of East Pit sample. These results disagree with results found by [8] who managed to get Pb recoveries of 80% at a lower grade. This could be due to the higher mass pull which included the carbonaceous materials reporting to the Pb stage as they did not have the Pre-stage float in their investigation.

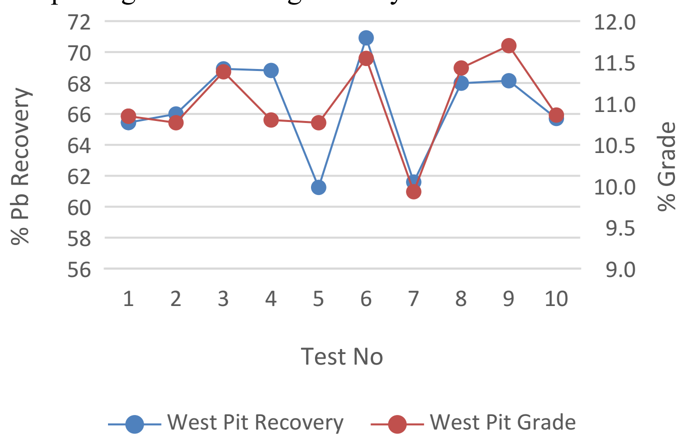

Fig 5: West Pit galena flotation stage

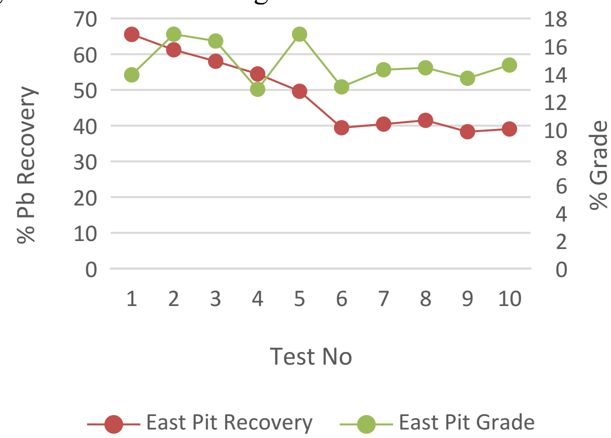

Fig 6: East Pit galena flotation Stage

3.5.3 Zn flotation stage

Both samples had similar Zn recoveries in the Zn flotation stage (Fig 7 and 8). East Pit had slightly higher recovery of 92.5% with a grade of 36.2% than West Pit which had 89.6% recovery at a grade of 23%. The following conditions used on the Zn stage, (800g/t $CuSO_4$, 80g/t SIPX and 30g/t Hydrofroth), seems to be the best minimum conditions which favours the Zn stage recovery with the less Zn being lost on the tailings. These results agree with the results by [9] where a recovery of more than 80% Zn was achieved using SIBX as a collector.

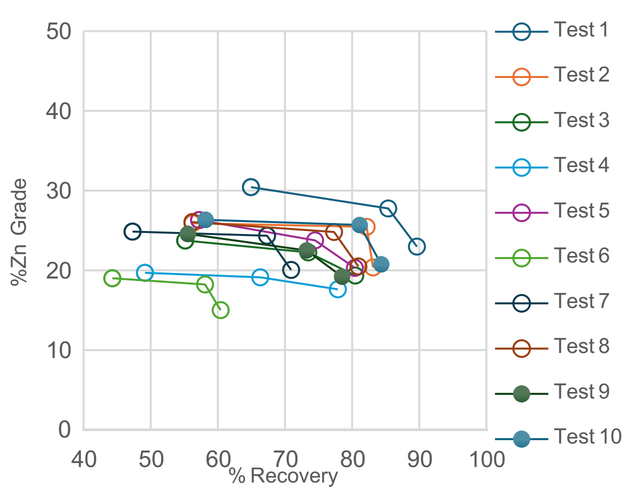

Figure 7: West Pit sphalerite flotation stage

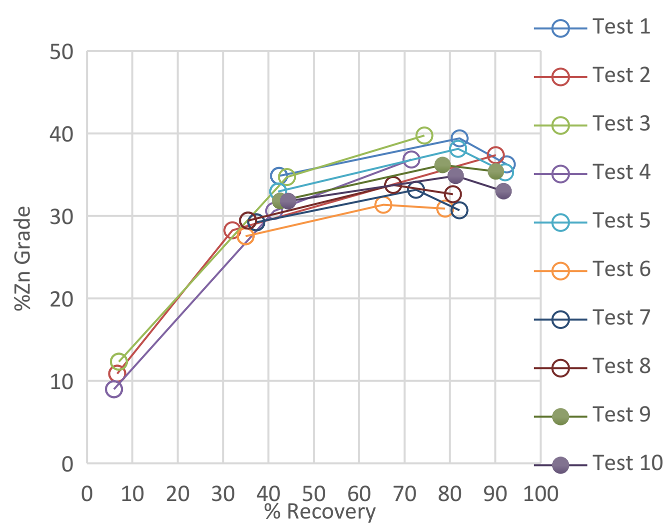

Figure 8: East Pit sphalerite flotation stage

3.6 Cleaner Flotation Stage Tests

The best optimum conditions from the rougher stages were used to conduct the cleaner stages. The Pb concentrates was further milled to 80% passing 25 while Zn concentrate was milled to 80% passing 38microns.

Samples from the West Pit performed better with the highest Pb recovery of 55.8% and a grade of 6.7% than East Pit samples with 43% and lower grade of 3.1% as shown in Fig. 9 below.

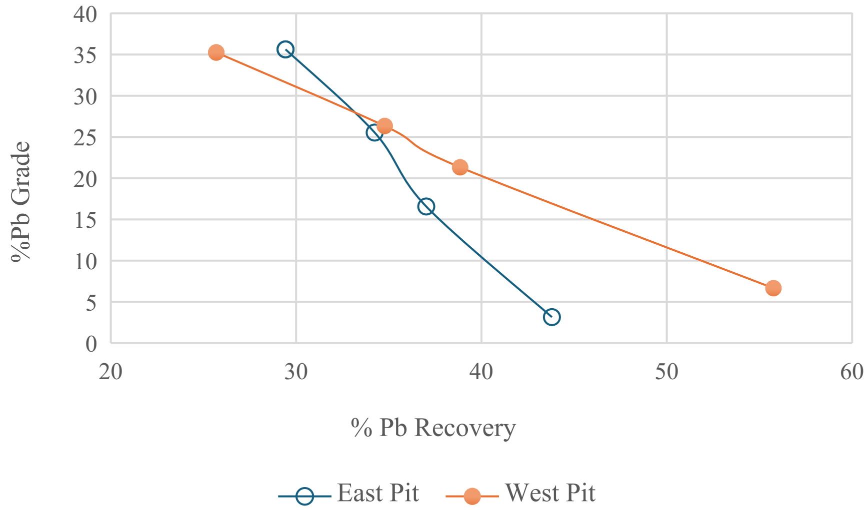

Fig 9: Pb Recovery vs Grade of the two samples in the cleaner stages

In Fig. 10 below, the East Pit samples showed higher Zn recovery percentages of 85.1% compared to the West Pit samples which had a moderate decrease in grade as recovery increases, maintaining higher grades overall in the Zn stage. The West Pit sample displayed a lower recovery percentages (generally below 80%) and experiences a sharper decline in grade with increased recovery compared to the East Pit samples.

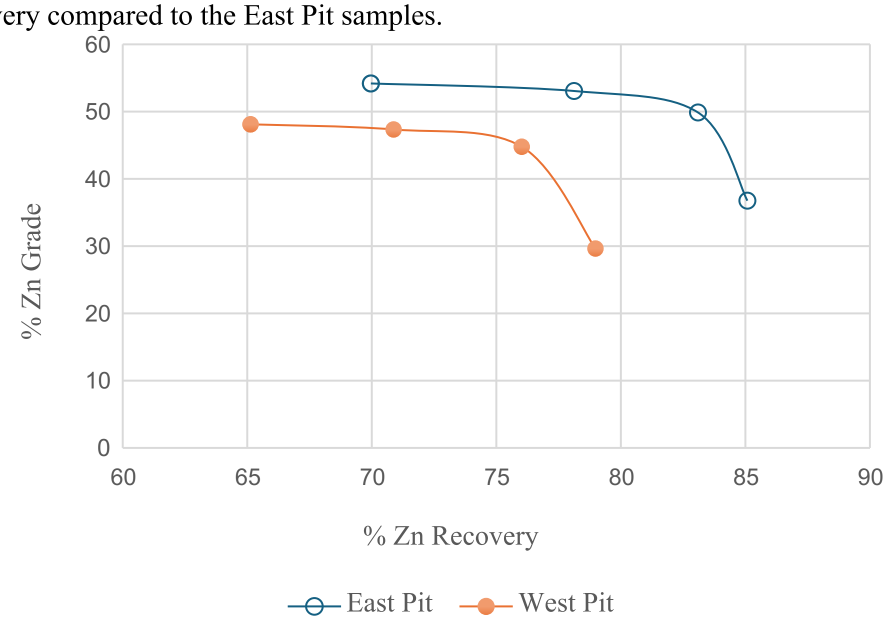

Fig 10: Zn Recovery vs Grade of the two samples in the cleaner stages

4. Conclusion

A Four stage flotation process was applied for the recovery of Pb and Zn from a polymetallic sulphide base metal ore containing carbonaceous minerals. Two different samples namely East and West Pit samples were investigated in the study. West Pit sample was found to be easy to treat in the carbonaceous and Pb flotation stages while East Pit was difficult to treat with lower recoveries and grades achieved in the carbonaceous and Pb flotation stages. Samples with high carbonaceous material content performed poorly in the carbonaceous gangue removal stage and consequently in all the subsequent flotation stage. However, the carbonaceous gangue removal stage improved the overall grade and recovery of both the high and low carbonaceous samples.

.

Acknowledgements

The authors would like to acknowledge one of the mines in the Northern Cape province of South Africa for providing the samples and SGS for funding the project.

Reference

[1] S. Bulatovic, " Handbook of flotation reagents: chemistry, theory and practice:," flotation of sulfide ores, p. Vol 1, 2019.

[2] Y. Mu, Y. Peng and R. A. Lauten, "The depression of pyrite in selective flotation by different reagent systems:," A literature review," *Miner. Eng*., pp. 143-156, 2022.

[3] N. Nkosi and W. Nheta, " Pretreatment and recovery of base metals from oxidised ores by froth flotation technology–A review," *Miner. Eng.,* vol. 218, pp. 109024, 2024.

[4] F. Abdolrahim, A. Majid, H. Zadeh, K. Yaser and G. Mahdi, ""Critical importance of pH and collector type on the flotation of sphalerite and galena from a low grade lead–zinc ore".," *Sci. Rep.*, pp. 1-11, 2023.

[5] D. Pashkevich, L. Pereira, O. Kökkılıç and K. Waters, " Froth flotation study of Pb-Zn ore under different temperature constraints," *Miner. Eng.,* vol. 232, p. 109534, 2025.

[6] V. Bragin, E. Burdakova, N. Usmanova and A. Kinyakin, "Comprehensive assessment of flotation reagents by their influence on metal losses and flotation selectivity," *Russ. J. Non-Ferr. Met.,* vol. 62, pp. 629-636, 2021.

[7] T. Baloyi and W. Nheta, "The Effect of Water Circulation on Bulk Flotation Performance of a Polymetallic Sulphide Ore," in *Proceedings of the 6th International Conference of Recent Trends in Environmental Science and Engineering (RTESE'22),* Niagara Falls, Canada, 2022, pp 191.1 – 191-8.

[8] S. Song, A. Lopez-Valdivieso, J. Reyes-Bahena and C. Lara-Valenzuela, "Floc flotation of galena and sphalerite fines.," *Miner. Eng., vol.* 14, no. 1, pp. 87-98, 2001.

[9] S. Nanda, S. Kumar and N. Mandre, " Flotation behavior of a complex lead-zinc ore using individual collectors and its blends for lead sulfide," *J. Disper. Sci. Technol.,* vol. 44, no. 9, pp. 1703-1710., 2023.