Scavenging of Niobium Pentoxide from Pre-Scrubbed Columbite Tailings at Varying Sieve Size for Industrial Application

[1]Oreoluwa Adeoye, [2]Oladunni O. Alabi, and Yemisi E. GbadamosI[3]
[1, 2, 3] Metallurgical and Materials Engineering Department,
School of Engineering and Engineering Technology,
Federal University of Technology, Akure, Ondo State, Nigeria
aoalabi@futa.edu.ng |gbadamosiyemisi.e@gmail.com

Received: 07-NOV-2023; Reviewed: 10-JUNE-2024; Accepted: 11-JUNE-2024
https://dx.doi.org/10.4314/fuoyejet.v9i2.20

ORIGINAL RESEARCH

Abstract— This study focuses on employing a cross-belt magnetic separator at various sieve sizes to upgrade the processed tailings of Kuru columbite ore for industrial application. The aim is to improve the quality of the processed tailings of the desliming process of the Kuru columbite (Plateau State) scrubbing method toward niobium pentoxide recovery by removing impurities through a cross-belt magnetic separator. The process was carried out at varied sieve sizes ranging from 500 to 125 µm. The cross-belt magnetic separator effectively removed ferromagnetic minerals (Niobium pentoxide) from the processed tailings, leading to a higher purity of the resulting mineral (48.326% Nb_2O_5) at 250 µm. Therefore, a 250 µm sieve fraction is recommended for its high grade, highest enrichment ratio, highest concentration ratio, and relatively low recovery. The study findings are helpful for niobium pentoxide production from columbite ore processing technology optimization, particularly in the context of industrial applications.

Keywords— Cross-Belt Magnetic Separator, Processing, Columbite Ore, Recovery

1 Introduction

Minerals are crucial for human growth and development, and their processing involves preparing ore, milling, and beneficiation. This process reduces ore transportation and costs by using cost-efficient, low-energy physical methods to separate minerals from gangue minerals, thereby reducing the amount of ore needed for smelting (Wills & Finch, 2015; Balasubramanian (2017).

Columbite, a natural solid mineral found in northern Nigeria, was a major exporter before crude oil discovery. Located in Plateau, Kogi, Kano, Nasarawa, Kaduna, and Bauchi states, it is a niobium-tantalum mineral with niobium being more abundant than tantalum (Baba *et al*., 2018). Columbite, a material with higher niobium oxide content than tantalum oxide, is used in various industries like capacitors, telecommunication, medical devices, and aerospace due to its diverse applications (Alabi *et al*., 2016). The study area for this project is a village known as Kuru which is located in Jos South Local Government Area of Plateau State, Nigeria falls within the coordinates of latitude 9º49'59.98"N longitude 8º50'59.99"E measured using the global positioning system (GPS) (Alabi *et al*., 2021). Kuru is known for the mining of tin and columbite. Other minerals such as kaolin and Tantalum are also mined there (Alabi *et al*., 2021).

*Corresponding Author

Section D- MATERIAL/CHEMICAL ENGINEERING & RELATED SCIENCES
Can be cited as:
Adeoye O., Alabi O.O., and GbadamosI Y.E. (2024): Scavenging of Niobium Pentoxide from Pre-Scrubbed Columbite Tailings at Varying Sieve Size for Industrial Application, FUOYE Journal of Engineering and Technology (FUOYE**JET), 9(2), 293-298.** https://dx.doi.org/10.4314/fuoyejet.v9i2.20

1.1 Magnetic separation techniques in mineral processing

Magnetic separation in mineral processing is primarily used to concentrate magnetic components and remove impurities under wet or dry conditions. (Chen & Xiong, 2015). The magnetic separation process involves passing a slurry that contains magnetic and non-magnetic particles through a non-homogenous magnetic field, leading to the selective capture of magnetic particles from the mixture. (Chen & Xiong, 2015). All materials display certain magnetic properties in the presence of an external magnetic field; however, only a minimal number of minerals are sensitive to magnetic fields and separable with magnetic techniques (Toyohisa, 2019; Bowman, 2023).

Based on this property the minerals are classified into three categories: Ferromagnetic: strongly attracted by the magnetic field; Paramagnetic: weakly attracted by the magnetic field; and Diamagnetic: shows weak repulsion magnetic fields of external nature (Amanda *et al*., 2013).

Diamagnetic: Diamagnetic minerals, composed of diamagnetic ions with closed shells, are repelled by magnetic forces, making them unfocused due to the minute forces involved (Amanda *et al*., 2013). Magnetic minerals, containing unpaired electron spins, are drawn to stronger fields due to magnetic pull, and high-intensity magnetic separators can concentrate these minerals. **Ferromagnetism** is a form of paramagnetism where strong forces cause spins in certain minerals to align parallel, demonstrating that permanent magnetization can persist even without an external magnetic field (Métioui, 2022).

1.1.1 Common Types of Magnetic Separators Used for Concentration

Ore Cobbing, Magnetic Drums, Induced Roll, Cross-belt, Ring Type, Low-Intensity Wet Drum, High-Intensity Wet Drum, and Super Conducting Separators (Qin *et al*., 2018; Kharlamov, 2018). Improving the efficiency of dry separation tailings of metallurgical production is possible due to the overlapping processes of magnetic extraction of ferrous particles and air stirring separating the material (Yamalov *et al*., 2015; Sharapov *et al*., 2016).

The array of applications makes columbite expensive and its occurrence is rare in nature (Baba *et al*., 2018) hence this study tends to improve the processing of columbite ore by using the induced magnetic effect separation technique.

2 MATERIALS AND METHOD

2.1 Materials

The material used for this research was the crude sample of Kuru Columbite, Plateau State, Nigeria

2.2 Method

The experimental procedure that was followed in carrying out this research study includes;

2.2.1 Sample collection

Kuru columbite tailings sample was retrieved for Niobium Pentoxide recovery from the desliming process. Samples were homogenized for chemical characterization analysis using a hand-held shovel.

2.2.2 Magnetic Separation

Magnetic separation experiments were conducted on the samples using a Cross-belt magnetic separator on the representative samples of sieve fraction -500+355, -355+250, -250+180, -180+125, and -125+90 µm.

A sieve fraction sample with magnetic and non-magnetic particles is fed into a cross-belt magnetic separator hopper. The sample enters through a vibrating tray, which distributes it across the load. The sample is then directed to the fluidized bed separator conveying tray, where it is moved by scrapers to the non-magnetic particle zone. The lower branch of the belt conveyor draws from a mixture of magnetic particles (Qin *et al*., 2018; Kharlamov, 2018). The procedure was repeated for the other sieve fraction and the resulting products (Magnetic: Iron, Ferromagnetic: Columbite, and Nonmagnetic: Tailings) were weighed, sampled, and analyzed for the determination of their chemical composition

3 RESULTS

Table 1: Chemical Analysis of the Tailings Processed Samples of Kuru Columbite Ore (Alabi *et al*., 2021)

Sieve Size Range	SiO_2	Fe_2O_3	ZrO_2	Nb_2O_5	TiO_2	ThO_2	Ta_2O_5	HfO_2	PbO
-500+355	26.0	22.01	27.1	12.1	1.55	2.43	1.04	1.24	0.15
-355+250	27.0	20.48	33.6	15.9	1.37	2.91	1.25	1.71	0.12
-250+180	23.0	24.36	BDL	16.6	1.63	3.73	1.49	1.73	0.14
-180+125	22.0	23.16	32.1	17.6	1.61	3.42	1.50	1.76	0.14
-125+90	21.0	22.26	BDL	14.4	1.45	3.46	1.39	1.71	0.14

Table 2: Weight of the Resulting Sample in Magnetic, Ferromagnetic, and Nonmagnetic of Kuru Columbite separated by the Cross-Belt Magnetic Separator.

Sieve Sizes (µm)	Crude (g)	Magnetic (g)	Ferromagnetic (g)	Non-Magnetic (g)
125	500	6.471	60.776	432.753
180	500	10.702	62.480	426.818
250	500	8.631	61.090	430.219
355	500	5.060	71.671	423.269
500	500	5.329	72.430	422.241

Table 3: Chemical Composition of the Resulting Sample in Magnetic, Ferromagnetic, and Nonmagnetic of Kuru Columbite separated by the Cross-Belt Magnetic Separator.

Sieve Sizes (µm)	Separator Arm	SiO_2 (%)	Fe_2O_3 (%)	Nb_2O_5 (%)	WO_3 (%)	Ta_2O_5 (%)	TiO_2 (%)	ZrO_2 (%)	SnO_2 (%)	PbO (%)	ZnO (%)	Ce_2O_5 (%)
125	Magnetic	11.640	47.687	6.707	0.093	0.860	17.610	4.726	0.370	0.173	0.089	0.470
	Non-Magnetic	60.238	5.116	2.108	0.032	0.247	0.632	24.159	0.237	0.046	0.032	0.344
	Ferro-magnetic	8.329	21.684	47.083	0.499	5.955	2.600	0.793	1.859	0.021	0.094	1.106
180	Magnetic	7.276	55.080	4.706	0.096	0.841	17.128	5.292	0.857	0.163	0.082	0.520
	Non-Magnetic	37.042	8.030	12.178	0.157	1.408	1.368	29.763	3.213	0.034	0.016	0.700
	Ferro-magnetic	7.983	23.845	46.805	0.464	5.190	1.966	1.246	1.429	0.070	0.086	0.772
250	Magnetic	9.340	52.832	4.519	0.067	0.676	19.349	3.169	0.826	0.170	0.103	0.414
	Non-Magnetic	58.386	6.117	3.051	0.059	0.277	0.347	25.414	0.386	0.056	0.003	0.376
	Ferro-magnetic	6.903	24.526	48.326	0.535	6.123	2.469	0.631	0.980	0.030	0.092	0.751
355	Magnetic	8.096	51.507	3.477	0.109	0.522	22.048	4.138	0.461	0.270	0.086	0.441
	Non-Magnetic	52.089	5.870	3.755	0.085	0.432	0.617	29.973	0.545	0.043	0.001	0.377
	Ferro-magnetic	9.146	24.473	43.830	0.502	5.371	2.913	1.018	1.145	0.043	0.113	0.844
500	Magnetic	8.308	57.651	3.762	0.035	0.279	17.039	3.615	0.443	0.217	0.105	0.589
	Non-Magnetic	55.279	5.718	4.108	0.103	0.615	1.359	24.345	1.111	0.059	0.001	0.409
	Ferro-magnetic	8.713	26.703	42.698	0.500	5.865	2.258	0.920	1.496	0.033	0.080	1.105

Table 4: Grade of Ferromagnetic (Niobium Pentoxide) in Kuru Columbite separated by the Cross-Belt Magnetic Separator.

Sieve Sizes (µm)	Processed Tailing (Crude) (%)	Magnetic (%)	Ferromagnetic (%)	Non-Magnetic (%)
125	17.6	6.707	47.083	2.108
180	17.6	4.706	46.805	12.178
250	17.6	4.519	48.326	3.051
355	17.6	3.477	43.830	3.755
500	17.6	3.762	42.698	4.108

https://dx.doi.org/10.4314/fuoyejet.v9i2.20 engineering.fuoye.edu.ng/journal

Table 5: Metallurgical Accounting Balance of Ferromagnetic (Niobium Pentoxide) in Kuru Columbite separated by the Cross-Belt Magnetic Separator.

Sieve Sizes (µm)	**Weight of Processed Tailings (g), (F)**	**Assay of Crude (%), (f)**	**Weight of Concentrate(Ferromagnetic) (g), (C)**	**Assay of ferromagnetic (%), (c)**	**Enrichment Ratio (c/f)**	**Concentration Ratio (F/C)**	**Recovery (Cc/Ff x100)**
125	500	17.6	60.776	47.083	2.68	8.23	32.52
180	500	17.6	62.480	46.805	2.66	8.00	33.23
250	500	17.6	61.090	48.326	2.75	8.23	33.55
355	500	17.6	71.671	43.830	2.49	6.98	35.70
500	500	17.6	72.430	42.698	2.43	6.90	35.14

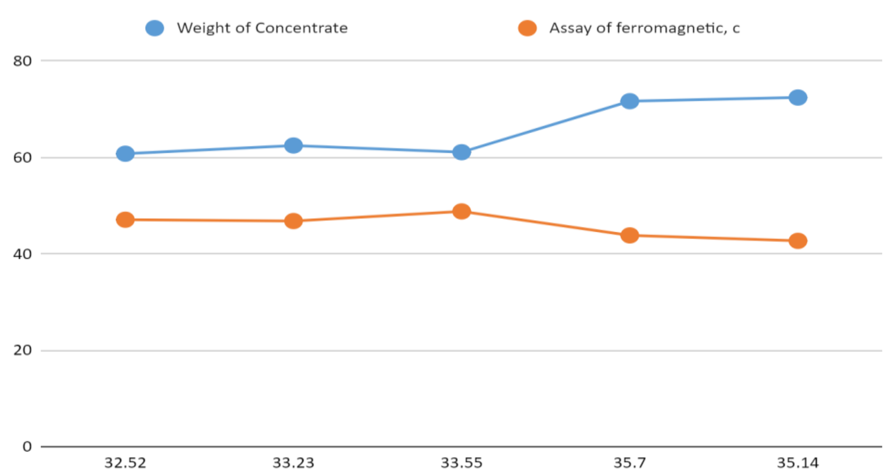

Figure 1: A Graph showing the Plot of the Weight of Concentrate (Ferromagnetic) and the Assay of Ferromagnetic against Recovery

https://dx.doi.org/10.4314/fuoyejet.v9i2.20 engineering.fuoye.edu.ng/journal

4 DISCUSSION

Table 1 shows the chemical composition of scrubbed columbite ore used in this research as crude, showing the percentage composition of different constituents found in the sample. It was observed that at -180+125µm sieve size fraction, Nb_2O_5 has the highest percentage composition compared to other sieve size fractions. The sample is composed of the following; SiO_2(22.0%), Fe_2O_3(23.16%), ZrO_2(32.1%), Nb_2O_5(17.6%), TiO_2(1.61%), ThO_2(3.42), Ta_2O_5(1.50%), HfO_2(1.76%), PbO(0.14%).

Table 2 reveals the weight of the resulting samples in magnetic, ferromagnetic, and non-magnetic of Kuru columbite separated by the cross-belt magnetic separator. The magnetic fraction is found to have the highest weight of 10.702g at a sieve size of 180µm and the lowest weight of 5.060g at a sieve size of 355 µm. The non-magnetic portion, however, becomes lesser in weight as the sieve size increases; the lowest weight of 422.241g was found at a sieve size of 500 µm, while the highest weight of 432.753g was found at a sieve size of 125 µm. The ferromagnetic fraction has the most weight of 72.430g at a sieve size of 500 µm and the least weight of 60.776g at a sieve size of 125 µm.

Table 3 shows the results of the chemical composition of the resulting sample in magnetic, ferromagnetic, and nonmagnetic Kuru columbite separated by the cross-belt magnetic separator. The chemical composition analysis shows a vivid variation between sieve size, separator arm, and the elemental composition of the resulting samples. For instance, the non-magnetic have higher concentrations of SiO_2 assaying 60.238%, ferromagnetic have higher concentrations of Nb_2O_5 assaying 48.326%, and the magnetic tends to have the highest concentration of Fe_2O_3 assaying 57.651%.

Table 4 reveals the grade of ferromagnetic (Niobium Pentoxide) in Kuru Columbite separated by the cross-belt magnetic separator. It was observed from Table 4 that the ferromagnetic sample is found to be most concentrated at a sieve size of 250µm (48.326%) and least concentrated at a sieve size of 500µm (42.698%). The magnetic is found to be most concentrated at a sieve size of 125µm (6.707%) and least concentrated at a sieve size of 355µm (3.477%). The non-magnetic has its lowest concentration at a sieve size of 125µm (2.108%), while the highest concentration was found at a sieve size of 180µm (12.178%).

Table 5 shows the metallurgical accounting balance of ferromagnetic (niobium pentoxide) in Kuru columbite separated by the cross-belt magnetic separator for better industrial application. The results indicate that the weight of the concentrate grew along with the sieve size with its peak at 500µm (72.430g). Correspondingly, the assay, enrichment ratio, and concentration ratio dropped significantly after 250µm. On the other hand, the recovery rose progressively up to sieve fraction 355µm with the highest recovery of 35.70. The results suggest that columbite can be efficiently concentrated and its industrial applicability enhanced by utilizing a cross-belt magnetic separator from a pre-concentrate of 16.6 %Nb_2O_5 to 48.326 %Nb_2O_5 at a sieve fraction of 250 µm. Figure 1 shows the plot of the weight of concentrate (ferromagnetic) and the assay of ferromagnetic against recovery, the graph reveals that as the sieve size increases, the recovery of ferromagnetic concentrates increases. The highest recovery was attained at a sieve size of 355 µm with a peak recovery of 35.70. The 250 µm sieve fraction can be recommended as it has the highest grade, highest enrichment ratio, highest concentration ratio, and relatively low recovery.

5 CONCLUSION

In conclusion, this study provides valuable information for the optimization of the cross-belt magnetic separation or double cross-belt magnetic separation processes in the future as well as for the use of columbite concentrates in practical applications.

The sample is composed of the following; SiO_2(22.0%), Fe_2O_3(23.16%), ZrO_2(32.1%), Nb_2O_5(17.6%), TiO_2(1.61%), ThO_2(3.42), Ta_2O_5(1.50%), HfO_2(1.76%), PbO(0.14%).

The magnetic fraction has the highest weight at 180µm and the lowest weight at 355µm. The non-magnetic portion decreases in weight as the sieve size increases. The ferromagnetic fraction is most concentrated at 250µm (48.326%), while the magnetic is most concentrated at 125µm (6.707%). The highest concentration is at 180µm (12.178%). The highest recovery is at 355µm with a peak recovery of 35.70, suggesting efficient concentration and enhanced industrial applicability using a cross-belt magnetic separator. The 250 µm sieve fraction is recommended for its high grade, highest enrichment ratio, highest concentration ratio, and relatively low recovery.

The results demonstrate that the cross-belt magnetic separator can successfully extract ferromagnetic particles, primarily Niobium Pentoxide, from the processed tailings of Kuru Columbite, supporting the claim that its industrial application has improved.

The study only explores more on the scavenging of valuables that escape into the tailing during processing for further industrial application.

Acknowledgement

The authors express gratitude to the Federal University of Technology Akure's Mineral Laboratory for allowing their research bench work and the National Metallurgical Development Centre, Jos, for characterizing the ore.

REFERENCE

Abere, D. V, Oyatogun, G. M., Abioye, A. A., Rominiyi, A. L., Abioye, O. P., Yaskuma, U., Onotu, G. O., Ogar, M. O., Oyatogun, A. O., Igbonwelundu, M. T., Filusi, G. F., and Akinwole, I. E. (2017). Comparative Study of Local Mining Methods and Assay of Cassiterite with Other Alluvial Mineral Deposits in Kuru-

Jantar, Plateau State, Nigeria. *American Journal of Mining and Metallurgy*, 4(1), pp. 51–61.

Alabi, O.O., Gbadamosi, Y. E., and Akinpelumi, T. (2021). Desliming process of kuru columbite (Plateau state) using scrubbing method towards niobium pentoxide recovery. *International Journal of Engineering Research Updates*, pp.43-49.

Alabi, O. O., Yaro, S. A., Dungka, G. T., Asuke, F., & Hassan, B. (2016). Comparative Beneficiation Study of Gyel Columbite Ore Using Double Stage (Magnetic-to-Magnetic and Magnetic-to-Gravity) Separation Techniques. *Journal of Minerals and Materials Characterization and Engineering*, 04(02), pp. 1-16.

Amanda Luzia da Silva, Arno Heeren de Oliveira, and Maria Lourdes Souza Fernandes (2013). Magnetic Separation as a Method to Assist Mineralogical Characterization of Rocks by X-Ray Diffraction, *International Nuclear Atlantic Conference - INAC 2013 Recife, Brazil*, pp. 1-10.

Baba, A. A., Jacob, S. O., Olaoluwa, D. T., Abubakar, A., Womiloju, A. O., Olasinde, F. T., and Abdulkareem, A. Y. (2018). Processing a Nigerian columbite-rich ilmenite ore for improved industrial application by sulphuric acid solution. *Indonesian Mining Journal*, 21(1), 9–19.

Balasubramanian, A. (2017). Gravity Separation in Ore Dressing. *ResearchGate*, pp 1-9.

Bowman, Frank (2023). “Magnetic Separation: A Comprehensive Overview.” *Ind Eng Manag*, 12, pp. 195.

Chen, L., and Xiong, D. (2015). Magnetic Techniques for Mineral Processing. *In Progress in Filtration and Separation*, pp. 1-23.

Kharlamov, E. (2018). Determination of the magnetic separator separation function, *MATEC Web of Conferences*, 251, pp. 1-8.

Métioui, A. (2022). A Brief Historical Review about Magnetism: From the Ancient Greeks up the Beginning of the XXth Century, *J. Biomed Res Environ Sci.*, 3(9), pp. 1101-1107.

Qin Xing, Zong Luo Zhen Fu, Lv Bo (2018).Variables and Applications on Dry Magnetic Separator, *E3S Web of Conferences*, 53, pp. 1-9.

Sharapov, R.R., Kharlamov, E. V. and Yadykina, V. V. (2016).The fluidized bed separator, *IOP Conf. Ser.: Mater. Sci. Eng.*, 324, pp. 1-12.

Toyohisa Fujita (2019). Magnetic Separation, Powder Technology Handbook *CRC Press*, pp. 1-12.

Wills, B. A., and Finch, J. A. (2015). Wills’ mineral processing technology: An introduction to the practical aspects of ore treatment and mineral recovery, pp. 23-50.

Yamalov D. R, Salakhov R. R, Gureev V. M, Salakhov I. R, Makarov A. N and Burlakov V.V (2015). Experimental Study of Heat Transfer in the Cooling Jacket of ICE KAMAZ, *International Journal of Applied Engineering Research-IJAER*, 10, pp.44982-44991.

https://dx.doi.org/10.4314/fuoyejet.v9i2.20 engineering.fuoye.edu.ng/journal