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DEVELOPMENT OF A WET MAGNETIC-GRAVITY PROCESSING ROUTE TO RECOVER COLUMBITE FROM JOS MINESFIELD TAILINGS DUMP, NIGERIA

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Abstract

Samples of the large Jos Minesfield tailings were subjected to microscopic, sieve and chemical analyses. The <1 mm undersize of the ore was fed into the wet high intensity magnetic separator (WHIMS) at pulp density, feed and flow rates of 1.33 kg/m^3, 250 kg/h and 188 m^3/h, respectively; to yield middlings, rougher and pre-concentrate. The sun-dried 355 µm WHIMS undersize of the mixture of middlings, rougher fraction and the pre-concentrate was then wet gravity concentrated on the Wilfley shaking table to give the concentarate, middlings, tailings and rougher concentrate. The middlings obtained from the Wilfley shaking table was further recycled. The products obtained were also subjected to chemical analysis. The results obtained showed that the sub-hedral columbite assayed 12.5, 45.5 and 2.95 % in the tailings as-received, the final concentrate and final tailings respectively, with 2.30% silver oxide. The recovery and separation efficiency of the process were determined as 58.47 and 51.4 %, respectively. The good recovery of silver oxide and the reasonable operating efficiency makes the wet processing route economic and acceptable for the tailings dump.

Key words: *Tailing dump, columbite, recovery, concentration, characterization, magnetic, gravity.*

1. Introduction

Recent economic and technological changes in mineral processing have enabled old dumped tailings of columbite to become profitable to process again. Columbite contains oxide of niobium (Nb_2O_5) and oxide of tantalum (Ta_2O_5) in different proportions. When the niobium oxide is much more than the tantalum oxide, the mineral is called columbite {$(Fe,Mn)Nb_2O_6$}, while it is called tantalite {$(Fe,Mn)Ta_2O_6$}, when the tantalum oxide content is much higher [1]. Niobium metal is best known in connection with High Strength Low Alloy steels (HSLA),

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heat resistance alloys in aerospace, vehicle engines and supersonic air-crafts [2]. Columbite is one of the most important solid minerals traded in the world market. Hence, many miners and processing engineers find one way or the other to acquire mining area rich in this mineral.

Millions of tons of the tailings of columbites and cassiterites mined at the Rayfield minesfield by the British Miners in the late sixties were still very rich in the mineral [3]. In the past, when mining and processing of columbite and cassiterite were done at this minesfield, less attention was given to the tailings either because their uses were not well defined then or there was no appropriate method of beneficiating them. Little was it known that the discarded tailings of the columbite would be of economic importance in today's local and international market.

Columbite is the main important mineral form of niobium. The columbite ore dressing usually involves pre-concentrate and concentrate clean-up. In order to recover columbite, Zlagnean and Sarpong [4] designed a flowsheet, which combines magnetic with gravity processing. The choice of any part of or the entire processing route would depend on the nature of the ore, particularly the content of Nb_2O_5 and Ta_2O_5 in the ore relative to its associated minerals and impurities and difference in their physical properties. The concentration processes may be carried out by wet or dry gravity, magnetic or electrostatic methods to produce concentrates containing up to 70 % combined pentoxide (Nb_2O_5 and Ta_2O_5) to meet extraction requirements. However, the universally employed method for the concentration of columbite ores are magnetic and gravity [5]. Solid minerals are so important in the production of materials for different engineering applications, that today's mineral processing engineering encourages the optimum method of beneficiating tailings for maximum secondary recovery, leaving little or no values in the final tailings [6].

Attempts to recover the columbite value of the Jos Minesfields tailings dump have been extremely difficult due to unsuitable processing methods of sieving, magnetic and gravity concentration adopted. This has discouraged further investment by mineral speculators and peasant miners on the dump site. This study is therefore initiated to develop a wet processing route for efficient secondary recovery of columbite from this mine waste. The success of this study will lead to the conversion of the waste tailings to wealth.

2. Materials and Methods

2.1. Materials

The material used for this study was the tailing collected from columbite tailing dump located in Rayfield village, about 15 km from Jos, Plateau State, Nigeria.

2.1.1. Sample collection

The sample of the Rayfield tailings dump was collected from the site using grab sampling method. One hundred and ten kilogram (110 kg) of the columbite tailings was picked randomly as the representation from the tailing dump.

2.1.2. Sample preparation

Using cone and quartering method, 110 kg of the tailings was poured into a conical heap, flattened and divided into four identical parts using a metal cutter. Two opposite corners were taken as sample; the other two corners were kept aside. The portion chosen as the sample was further coned and quartered, and this continued until a sample of 500 g of the columbite tailings was obtained.

2.2. Methods

The representative sample obtained was subjected to microscopic and sieve analyses, wet magnetic/gravity technique and energy dispersion X- ray fluorescence spectrometry technique.

2.2.1. Microscopic analysis

The Rayfield columbite tailing was characterized microscopically, using Leica Petrographic microscope model No. DMRX/MP60. Loose crystals of the ore were spread on a glass slide for viewing under microscope. The mounted particles were studied under the reflected microscope at 200X magnification. The incident light beam was refracted back to the eye-piece of the microscope for viewing and studying. The grain size, shape and colour of more pronounced minerals in the tailings were identified.

2.2.2. Sieve analysis

The sieving or screening was done using sieve sizes of 1, 0.85, 0.710, 0.5, 0.355, 0.250, 0.180, 0.125 and 0.09 mm. The sieves were arranged using geometric progression based on $\sqrt{2}$ with the sieve with the largest aperture on top. The 500 g prepared sample of the tailing was placed on the topmost screen and the nest of sieve was automatically vibrated for 20 minutes. The sieves were taken apart and the ore retained on each sieve was weighed. The results obtained in terms of percent weight retained on each sieve are presented in tabular form [7]. 50 kg of the columbite tailings was sieved using the 1 mm sieve, the oversize was further crushed using roll milling machine to obtain 100% -1 mm sample.

2.2.3. Magnetic Concentration

The undersize obtained was fed into the wet high intensity magnetic separator (WHIMS), KDH Humboldt Wedag Model P40, with an operating current of 2.6A, pulp density of 1.33 kg/m^3 and at a feed and flow rate of 250 kg/h and 188 m^3/h, respectively [3]. The WHIMS processing of the ore yielded middlings (consisting of columbite, silica, zircon and iron), rougher (silica, zircon and columbite) and pre-concentrate (columbite, iron and zircon). The middlings was then combined with the rougher and sun-dried for 30 minutes before sieving through 355 μm sieve. The oversized fraction was milled until all passed through the 355 μm sieve.

2.2.4. Gravity Concentration

The -355 μm fraction obtained was then fed into the Wilfley shaking table, Denver Model 5614 operated at a tilted angle of 60°, speed of 2.75 stroke/s, motor speed of 1425 rpm. The processing gave the concentrate, tailings and rougher concentrate, while the middlings obtained from the Wilfley shaking table was recycled as presented in the wet processing flowsheet (Figure 1). Representative samples of rougher, pre-concentrates, rougher tailings and rougher concentrate were afterwards selected for chemical analysis.

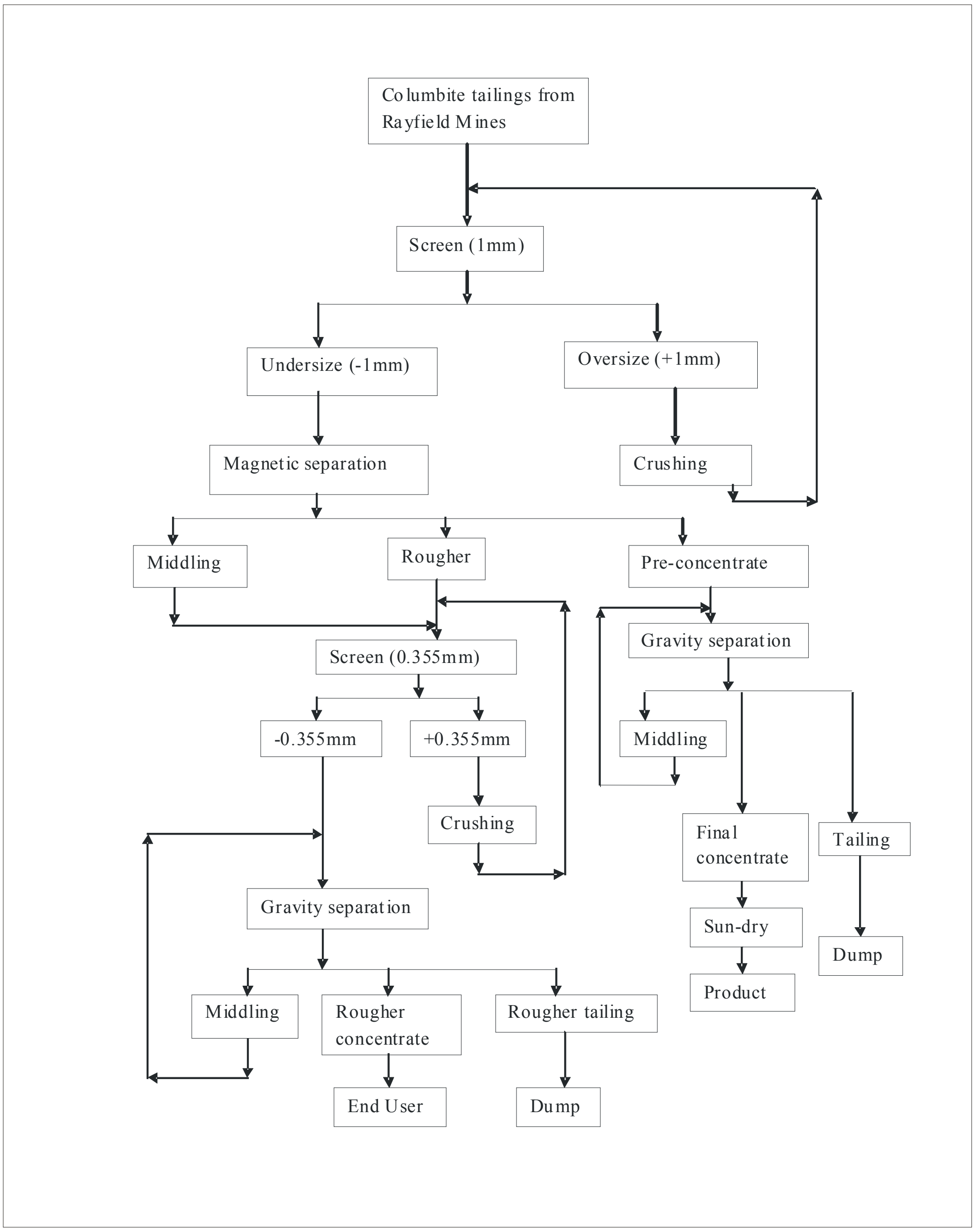

Figure 1. *The wet processing flowsheet*

The pre-concentrate of the WHIMS was also fed into the Wilfley shaking table for gravity separation to obtain the final concentrate and the pre-concentrate final tailings. The middling and pre-concentrate tailings were then combined and recycled using the shaking table. The pre-concentrate tailing was combined with the rougher tailing to form the final tailing of the wet process. Then the samples of each processing unit were taken for analysis using coning and quartering method.

3. Results and discussion

3.1. Results

The result of the microscopic and sieve analyses are presented in Figure 2 (a, b and c) and Table 1, while the results of the chemical and ED-XRF chemical analyses are shown in Tables 2 and 3.

Metallurgical balance for wet processing and Recovery and separation efficiency for wet processing method are shown in Tables 4 and 5.

Figure 2a. *Microscopic view of grain size of the tailings 200×*

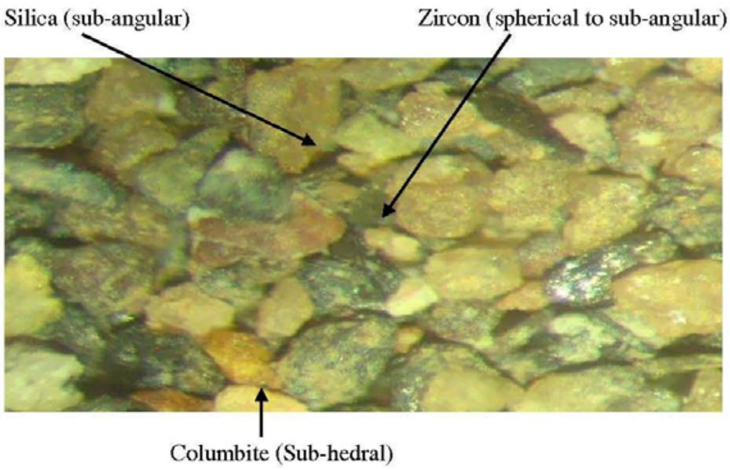

Figure 2b. *Microscopic view of the shapes of the compositions of the tailings 100×*

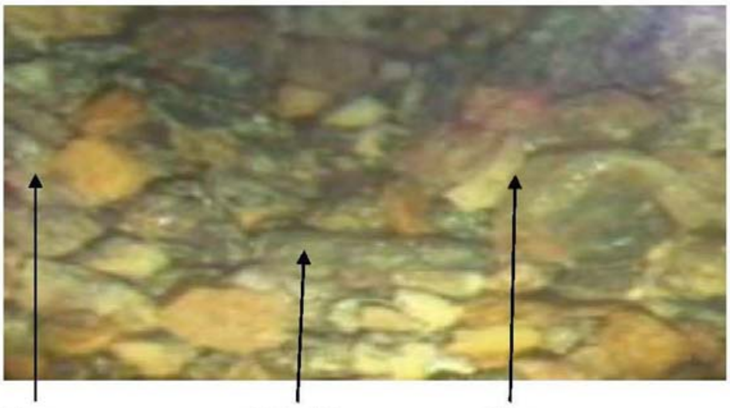

Figure 2c. *Microscopic view showing the colours of the composition of the tailings 100×*

Table 1. *Results of sieve analysis of the Rayfield tailing*

Sizes (mm)	Weight (g)	Weight Percentage (%)	Nominal aperture size (mm)	Cumulative weight (%) undersize	Cumulative weight (%) oversize	% Nb_2O_5	% Ta_2O_5
+1.00	6.04	1.2	1.00	98.8	1.2	0.3	0.0
−1.00+0.850	17.87	3.6	0.850	95.2	4.8	2.5	0.4
−0.850+0.710	49.79	10.0	0.710	85.2	14.8	3.8	0.7
−0.710+0.50	75.41	15.1	0.50	70.1	29.9	8.2	1.1
−0.50+0.355	101.55	20.3	0.355	49.8	50.2	11.4	1.5
−0.355+0.250	137.47	27.5	0.250	22.3	77.7	16.8	1.9
−0.250+0.180	78.22	15.7	0.180	6.6	93.4	17.2	2.1
−0.180+0.125	23.29	4.7	0.125	1.9	98.1	16.1	2.1
−0.125+0.090	7.46	1.5	0.090	0.4	99.6	8.4	1.7
−0.090	2.06	0.4					
Total	499.16						

% Error = 0.17

Table 2. *Chemical analysis of Rayfield tailings by ED-XRFS*

Samples	Al_2O_3	SiO_2	TiO_2	Fe_2O_3	ZrO_2	Nb_2O_5	Ag_2O	Ta_2O_5	ThO_2
Rayfield Tailing Dump (-1mm)	4.70	40.3	0.74	12.90	7.80	12.50	1.90	1.90	2.78
Wet pre-concentrate	1.60	5.01	0.69	15.49	2.70	45.20	0.84	0.04	0.52
Wet final concentrate	1.06	6.00	0.81	14.47	18.50	45.50	2.30	3.17	0.55
Wet rougher concentrate	1.08	17.90	0.27	1.68	66.60	3.47	0.78	0.31	0.83
Final Tailings (Wet)	4.63	41.8	0.37	3.26	29.9	2.95	0.66	ND	0.96

ND = not detectable

Table 3. *Mass balance for wet processing*

Item	Wet (kg)
Feed	50
Final concentrate	8
Rougher concentrate	21
Final tailing	20
Loss	1.0

Table 4. *Metallurgical balance for wet processing*

Item	Weight (kg)	Assay (%)	Weight of Nb_2O_5 (kg)	Distribution of Nb_2O_5 (%)
Feed	50	12.5	6.25	100
Final Concentrate	8	45.5	3.64	58.2
Rougher Concentrate	21	3.47	0.73	11.7
Total Concentrate	29	15.07	4.37	69.9
Unaccounted Loss	–	–	1.3	20.8
Final Tailing	20	2.95	0.58	9.3

Table 5. *Recovery and separation efficiency for wet processing method*

Item	Wet Percentage (%)
Retrospective recovery	81.69
Check-in/check-out Recovery	58.47
Separation efficiency	51.4
Grade	45.5

3.2. Discussion of Results

The grain size of the crystals of the alluvial tailing was found to be between 0.2 to 0.85 mm (Figure 1a). This made the tailing to be fine to medium size. Under the microscope, it was observed that the particles' shapes vary from spherical to sub-angular for silica, sub-hedral for columbite and spherical to sub-angular for zircon (Figure 1b). The colours were also identified under the microscope as dull grey to colourless, grayish dark and light brown to yellowish for silica, columbite and zircon, respectively.

After the characterization, columbite was suspected to be present in the tailings because of the number of grayish dark colour grains that dotted the sample under the microscopic view (Figure 1c).

The screen distribution analysis showed that 88.60 % of the tailing is found in the size fractions -850+710 μm to -250+180 μm with the highest percent of 27.50 % being retained in the range -355+250 μm which was selected for the processing as shown in the process flowsheet for the wet processing technique. The median size was determined to be in the region of 0.355 mm. From the sieve analysis, it can be seen that

98.8 % of the tailings passed through 1.00 mm sieve, hence the use of the sieve size to cut off bigger grain size and subsequent crushing of the oversize to pass through the sieve for both dry and wet processing [8]. The visual observation and EDXRF analysis of the -1 mm sieve fractions of the Rayfield tailings, showed that both niobium and tantalum are sufficiently liberated and could easily be concentrated. In addition, the coarse alluvial formation of the Rayfield tailings waste reduces the time and cost of processing.

Chemical analysis showed that the Rayfield dump has silica, hematite iron, zirconia and columbite as its major constituents, thus indicating the need to use the differences in their physical properties for separation of columbite. Since hematite iron ore is a major impurity in the columbite tailings and WHIMS is designed to separate para-magnetics, both hematite and columbite reported to the collector pole as concentrates thus raising the Fe contents of the wet pre-concentrate and wet final pre-concentrate to 15.49 and 14.47 %, respectively. Dry and wet high gradient magnetic separation (HGMS) method has also been used to remove magnetic products from the Serbian Nikola Tesla B thermal power plant lignite fly ash increasing the Fe content from 3.20 % in the feed to 27.43 % in the concentrate. Similarly, the dry HGMS method was also applied to upgrade the Fe content of the Siderit iron works dust outlets from 26-28 % to 44.75 % and after further processing at higher magnetic field induction to as high as 76.13 % in a magnetic product [9, 10.] The final concentrate of the wet processing was found to contain about 2.30 % of the higher value silver oxide in addition to columbite. The results reported for dry processing route earlier showed that silver oxide was not detectable in the final concentrate [11]. The good silver oxide recovery obtained in the wet processing of the Rayfield tailings strongly suggest the method as being appropriate where the recovery of only silver is needed as an addition to columbite. The results of the chemical analysis further showed that the Rayfield tailings contain thorium oxide, while the final concentrates of the wet processing method contain very low or negligible quantity of this radioactive oxide. The lower content of thorium oxide in the final concentrate makes its handling safer and thus less costly.

The mass balance showed that 8 kg of columbite concentrate was achieved with 1.0 kg loss, while metallurgical balance gave the distribution of columbite in the final concentrate (the proportion of columbite in the feed that reported to the concentrate) as 77.9 % with a grade of 69.9 %. Combining the final concentrate with the pre-tailing concentrate, the grade dropped to 20.7 % and the distribution of the columbite in the total concentrate jumped to 86.2 %. The results indicated that the proportion of metals in the feed that reports to concentrate may have an inverse relationship with the grade. The results obtained from metallurgical balance thus strongly indicate that the wet processing route adopted is reasonably effective for the concentration of the Rayfield tailings dump.

The retrospective recovery method showed that the final concentrate of the wet processing method has grade and recovery percents of 45.50 and 81.70, while its total concentrate has 15.07 and 95, respectively. The trend of the results obtained confirmed the fact that an approximate inverse relationship usually occurs between recovery and grade of concentrates in all concentrating processes [7]. The recovery and separation efficiency for the wet magnetic/gravity route was 58.47 and 51.40 %, respectively. The recovery and separation efficiency results for the wet route compared poorly with 77.95 and 77.88 obtained for the dry route reported earlier [11].

4. Conclusion

Rayfield tailings have been characterrized based on difference in shapes and colours of the composition using Leica Petrographic Reflected Light Microscope, which showed the sub-hedral shape of columbite and its grayish-dark colour. The assaying of the tailing using ED-XRF spectrometry confirms 12.5 % of columbite with silica, zircon, iron, alumina and other associated minerals. A wet magnetic and gravity beneficiating route with a recovery and separation efficiency of 58.47 and 51.40 %, respectively has been developed. Though the wet processing route has been found to compare poorly with the dry in terms of recovery and separation efficiency, it has the advantage of higher recovery of the high value silver oxide.

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