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Adaptable Technologies for Life – Cycle Processing of Tantalum Bearing Minerals

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ABSTRACT

Nigeria is richly endowed in convertible natural resources of which solid minerals are a member of the endowments. However, the country is basically a mono-product economy based on its vast oil deposit accounting for over 84% of foreign earnings and 25% of GDP. The triple challenges of the volatile nature of global oil politics, achieving the objectives of the millennium development goals and the national economy empowerment and development strategies calls for diversification into hitherto neglected solid mineral deposits to open a window of opportunities. One of the widely reported mineral deposits in the country with strong international influence is tantalum-bearing mineral. The mineral had in the past few decades experienced a strong growth in demand averaging 10% per annum since 1992 with total world consumption estimated at over 38 thousand tonne in 2005. The total annual supply of the ore concentrate in 2001 was 720 tonnes when demand was 26 thousand tonnes. Thus, pushing the price of the concentrate to an all time high of $165 / kg in 2001.

This paper outlines the characteristics of the Nigerian tantalum reserves. It also presents the evaluation of the competing technologies for complete cycle processing of tantalum bearing minerals for adoption in the Nigeria solid mineral industry.

Keywords: *Adaptable technologies, life-cycle processing, tantalum bearing minerals.*

INTRODUCTION

Nigeria's endowments in fluid and solid minerals are extensive. The country's mineral development in terms of prospecting and exploitation has been largely focused on its oil and gas industry. The solid minerals sector has been neglected. Solid minerals constitute a wide-range of natural resources that provide a high developmental potential for a given country. They provide the bulk of raw materials for industry and have a high content of technological development input. The list of known minerals in Nigeria is impressive [1]. Unfortunately, knowledge is available for only about a third of the mineral [2]. Nigeria is Africa's largest oil producer and contributes about 3% to global production. Crude oil is therefore the bedrock of the country's economy. Oil production averages 84% of the annual foreign earnings of government and constitutes about 25% of GDP [3]. As a consequence of this, mining and other earth based economic activity has been neglected. Currently, prospecting and mining of solid minerals contribute just 1% to the country's GDP [4].

The volatile nature of global oil politics and economics calls for diversification into the hitherto neglected vast solid mineral deposit not only to widen the scope of the financial well being of the state but also to open a window of opportunities. Besides, the current structural reforms of the Federal Government as anchored in the National Economic Empowerment and Development Strategy (NEEDS) policy and the millennium development goals emphasize capacity building and self reliance in areas of comparative advantage in natural and national endowments in order to improve standard of living.

Nigeria tantalite endowment is impressive. The mineral is currently experiencing global boom.

Tantalite / Columbite – tantalite ore groups are the major sources of metal tantalum which is a refractory metal with distinct electrical, chemical and physical properties. The metal is used essentially as tantalum powder in a number of applications [5]. Some of the applications include but not limited to electronic capacitor, metal cutting tools, important addition to super alloys, camera lenses, chemical equipment. The use of tantalum has, for instance, been instrumental in reducing the size of mobile phones.

The upsurge in the application of systems and devices that uses tantalum bearing component as a unit has increased the demand for the primary tantalum ore concentrate. The mineral had in the past few decades experienced a strong growth in demand averaging 10% per annum since 1992 with total world consumption estimated at 38 thousand tonne in 2005[6]. The total annual supply of ore concentrate in 2001 was 720 tonnes when demand was 2,600 tonne. Thus, pushing the price of the concentrate to an all time high of $165/kg in 2001 compared to $14/kg in 1990. The supply has not kept pace with the demand.

The clear gulf in the supply-demand market situation of tantalum ore concentrate due to increase in devices, instruments and systems that uses capacitors to regulate voltage surge in high temperature and similar environment, particularly in the electronic, aviation and medical industries has made investment in prospecting, mining and beneficiating tantalite bearing mineral a worthy investment. The high premium in tantalum ore concentrate at the moment ($165/kg) gives a high rate of return on investment.

The wining of tantalum from tantalite ore concentrate via industrial extraction requires the establishment of tantalite processing plant adopting the best combination of production technology, competitive economic and environmental safety. The decision to invest in a tantalite processing plant is a function of many variables. Key element in these variables are investment cost in relation to industrial uses, evaluation of market trends and return on investment.

The paper characterizes the Nigerian tantalite reserves and evaluates competing technologies for complete cycle processing of tantalum bearing minerals for adoption in the Nigerian solid minerals industry.

GEOLOGY & GEO-CHEMISTRY OF TANTALUM BEARING MINERALS

Tantalum bearing minerals occur in pegmatite and other related mineral rock deposits as tantalite and microlite, nodgnite, columbite and struvenite. It is naturally discovered in pegmatite in conjunction with other economic minerals. Some of these are beryl, spodumene, feldspar, mica, scheelite, cassiterite, uraninite and monazite. Also, weathering and erosion of tantalite bearing primary deposits can mechanically enrich the tantalite into secondary alluvial deposits. The tantalum, tin and lithium minerals are derived from rare metal pegmatites dated radiometrically at 2.6 billion years[7]. The two main ore zones within the pegmatite are the albite (feldspar) zone containing tantalum/tin minerals and the spodumene zone containing high grade lithium minerals which generally occurs in enriched zone on the hanging wall of the principal pegmatite. The main pegmatite ore bodies occur along a strike length of 3.15km and generally dip to the west at 45-50 degrees.

Pegmatites bodies are complex in their composition and continuity. The distribution of the economic minerals in them is very erratic with the result that large amount of rock must be mined for a relatively small recovery of mineral. Most pegmatites consist of quartz, potash, soda feldspar and muscovite. Mineralization is chiefly associated with lenticular quartz bodies surrounded by alteration zones containing minerals such as kaolin, sericite, tourmaline, flurvite, beryl etc. The tantalite mineralization is usually concentrated in the quartz-rich part of the pegmatite. The highest grade of tantalum deposit occurs in pegmatite that contain relatively high concentrations of the tin mineral cassiterite and lithium mineral spodumene and anomalous concentration of beryl.

The mineral grain size in the pegmatite varies widely, ranging from less than 1mm up to 100mm. The economic minerals tantalite and cassiterite are normally very fine-grained and not visible in hand specimens. Spodumene occurs as microscopic grains through to lathes 2 millimetres long.

Tantalite is a compound of tantalum, iron and manganese and is often in association with columbite (a niobate of iron and manganese). However, tantalite minerals with over 70 different chemical compositions have been identified. Those of greatest economic value are tantalite, microlite, wodginite; though, it is common practice to name any tantalum – containing mineral concentrate as “tantalite” primarily because it is processed for the tantalum content and traded on that basis.

The general mineral composition of tantalite is (Fe, Mn) Ta_2 O_6, an oxide of iron, manganese and tantalite. Niobium substitutes for tantalum in all proportions; a complete series extends to columbite (Fe, Mn) Nb_2 O_6. Pure tantalite is rare. Iron and manganese vary considerably in their proportions [8].
Tantalite mineral varies between black and red-brown color, hardness of 6 on the Moh’s scale, specific gravity 5.2-8.0. It fractures uneven and luminescence varies from opaque to translucent or transparent.

GLOBAL PROFILE OF TANTALITE CONCENTRATE MARKET

Tantalum bearing minerals are sourced primarily from Australia, Canada, Brazil and Central Africa with some additional quantities from South East Asia, China, CIS countries, South America and sparingly Egypt and Saudi-Arabia. Nigeria is just about making entry into the supplying nations league and is reported as being the 7th tantalite (25metric tons) resource country in the world[9].

Figure 1 is the illustration of the base and economic reserves of some tantalite producing nations. The figure revealed that Australia and Brazil accounts for over 90% of the world’s base reserve. The economic reserve describe the actual production capacity while the base reserve is the total estimated tantalite endowments. The world acclaimed supplier of tantalite from Australia is Sons of Gwalia incorporated. The firm alone account for over 75% world production capacity.

Tantalum economic and base reserve rate for ten (10) year periods is presented in Figure 2. It is apparent from the figure that the rates have respectively increased from 35,000 and 22,000 ton in 1995 to 43,000 and150,000 ton in 2004 respectively.

There has been an average yearly growth rate of about 8-12% in tantalum demand since 1995 and this has caused a significant increase in exploration for the element (Figure 2). This yearly growth rate has put a pressure on the spot price tags for tantalum ore. The combined production capacity of the global producers and suppliers of tantalum cannot match the demand. There are ready recipients of processed tantalum concentrates. These are Brazil, Germany, Israel, Mexico and the United Kingdom [10].

The Nigeria tantalum reserve spreads across ten states comprising Niger, Nasarawa, FCT Abuja, Oyo, Gombe, Kaduna, Kwara, Kogi, Zamfara and Ekiti. The reserve is estimated at 25 metric tons. The deposits are both alluvial and primary pegmatites. Current production statistics is put at 80 tons in 2000 rising from 60 tons in 1997[11]. However, it is one of the solid minerals being aggressively marketed to both local and foreign investors for exploration and exploitation owing to its unique potential economic value [12].

MINERALOGICAL CHARACTERIZATION OF TANTALUM BEARING DEPOSITS IN NIGERIA

Several works [14-16] had been carried out on the mineralogical and compositional characterization of major tantalum bearing mineral deposits in the country. These works revealed the extensive abundance of elemental tantalum in association with niobium as the respective oxides. The mineralogical characterization as studied by Adetunji et al[16], being the most recent and extensive in terms of number of deposits investigated is re-presented in Table 1.

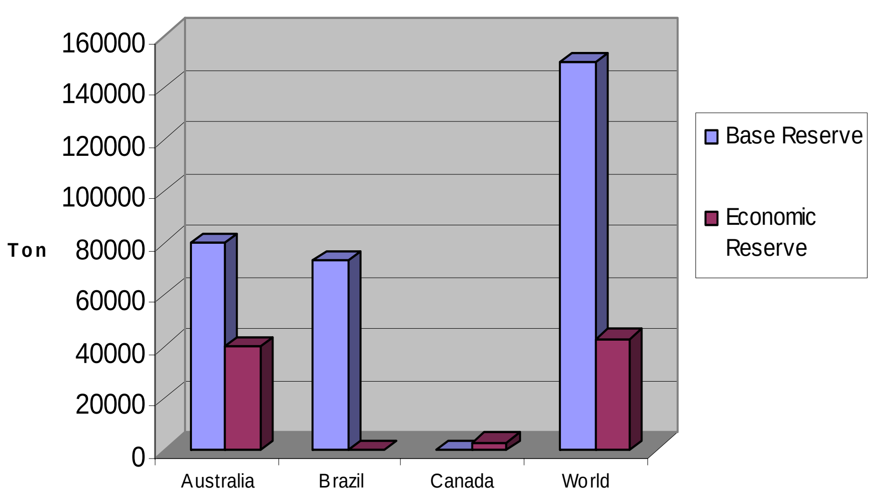

Fig. 1: The rate of base & economic reserve of tantalum in the World in 2004 (USGS) [13]

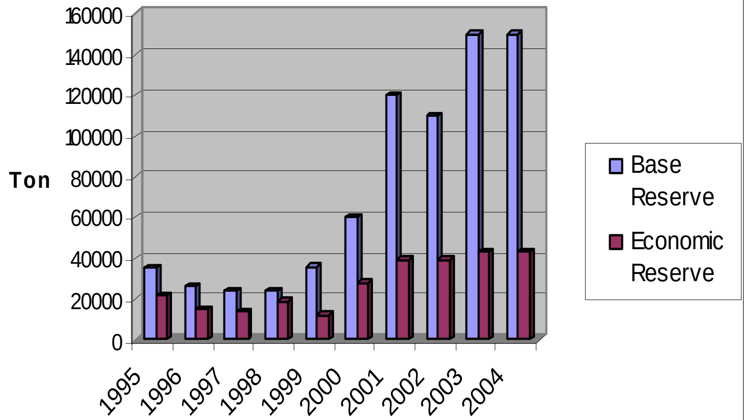

Fig. 2: The rate of base & economic reserve of tantalum in the World for ten year period (1999-2004) (USGS)[13]

Table 1: Mineralogical Analysis of Tantalum Ore Samples Form 8 Different Locations in Nigeria[16]

Oxide	Egbe	Komu	Nasarawa	Agunrege	Baba Ode	Ofiki	Igbo Ijaye	*Otu*
TiO_2%	-	-	3.81 ±0.42	1.64 ±0.37	2.34 ±0.42	1.05 ±0.33	20.36 ±0.58	*33.38 ±0.67*
MnO%	4.15 ±0.10	9.03 ±0.17	5.80 ±0.13	6.69 ±0.14	8.62 ±0.17	10.10 ±0.18	3.46 ±0.12	*0.74 ±0.09*
Fe_2O_3%	7.76 ±0.18	3.51 ±0.14	10.69 ±0.23	7.37 ±0.18	4.69 ±0.16	2.86 ±0.13	9.66 ±0.21	*9.70 ±0.20*
Ta_2O_5%	59.58 ±0.62	49.57 ±0.54	46.15 ±0.52	45.42 ±0.49	42.00 ±0.46	36.63 ±0.42	23.64 ±0.40	*8.00 ±0.17*
Nb_2O_5%	19.74 ±0.17	29.18 ±0.23	24.86 ±0.20	31.18 ±0.26	32.90 ±0.26	37.48 ±0.29	28.90 ±0.29	*22.43 ±0.17*
WO_3%	-	0.38 ±0.13	1.80 ±0.14	-	-	-	0.32 ±0.09	*0.17 ±0.05*
SnO_2%	-	-	8.43 ±1.97	-	-	-	-	-
Hf%	0.22 ±0.05	0.26 ±0.05	0.31 ±0.05	0.18 ±0.05	0.17 ±0.05	0.11 ±0.04	0.13 ±0.04	-
Zn%	-	0.22 ±0.03	0.09 ±0.03	-	0.09 ±0.03	0.07 ±0.02	-	-
Zr%	0.31 ±0.01	0.12 ±0.01	0.26 ±0.01	0.15 ±0.01	0.22 ±0.01	0.17 ±0.01	0.06 ±0.01	*0.06 ±0.01*
Pb(ppm)	489 ±146	570 ±146	1720 ±195	-	1010 ±168	720 ±146	-	-
Rb(ppm)	-	120 ±47	-	-	-	-	-	-
Y (ppm)	-	-	333±51	-	-	-	-	-
ThO_2%	0.34	0.03	0.15	0.02	0.02	0.05	0.03	*0.01*
U_3O_8%	*0.17*	*0.37*	*0.65*	*0.42*	*0.94*	*1.57*	*0.28*	*0.27*

The analysis of Table 1 revealed that the tantalite constituent in the various deposits range between 8.00-59.58% and niobium between 19.74-37.48%. The relative distribution of these two important constituents did not follow a rhythmic pattern. However, the combined distribution of these concentrates approximately range between 30.43-79.20%. Generally, concentrates exceeding 25% Ta_2O_5 do not require any pre treatment before concentration for tantalum recovery[17]. Since all the investigated deposits except Otu deposit contains more than 25% Ta_2O_5, they may be concentrated through clean-up concentrations while the Otu deposit will require pre-concentration before economic beneficiation could be embarked upon.

The titanium ore concentrate in two of the eight deposits is appreciable; Igbo Ijaiye – 20.36% and Otu 33.38%. The manganese ore and iron ore assays range 0.74% in Otu – 10.10% in Ofiki deposit and 10.69% in Nasarawa – 3.51% in Komu respectively. Impurity trace elements such as Hafnium (Hf), Zinc (Zn), Zirconium (Zr), Lead (Pb), Rubium (Rb) and Yttrium (Y) were present in their relative insignificant amount as presented in the table.

The implication of the characterization of the tantalite deposit is that during the planning of the beneficiation process for the primary concentration of the deposits for tantalite and/or niobium concentrate, adjunct process could be coupled to the main plant for secondary beneficiation of such constituents as TiO_2, MnO_2 and Fe_2O_3 depending on the quality of the deposits in terms of these secondary constituents. This is the underlying concept for the complete-life cycle processing techniques or what could be conveniently referred to as wasteless beneficiation technologies.

BENEFICIATION ROUTES FOR WASTELESS RECOVERY OF TANTALUM AND ASSOCIATED MINERAL CONCENTRATES

The beneficiation process adopted in concentrating a particular ore is a function of the nature of the ore in terms of physico-mechanical and chemical characteristics of the ore. Basically, there are three stages that are involved and these are pre-concentration, primary concentration and concentration clean up[18]. The choice of any or all of these depends on the characteristics of the ore (particularly the content of the principal concentrate) relative to associated minerals and impurities. The beneficiation process may be carried out by any or combination of the mineral beneficiation techniques. These techniques include wet gravity, magnetic, electro static and flotation and the associated contending technologies are pyrometallurgy, chlorination and hydrometallurgy. The correlation existing among the three variables of grades of tantalite, beneficiation and chemical extraction routes is provided in Table 2.

Table 2: Correlation between different Grades of Tantalite Ores, Beneficiation Routes and Chemical Extraction (milled from Adetunji et al[16])

Grades of Tantalite %	Raw-material input	Beneficiation Routes	*Chemicaal Extraction Route*
2-10	Low-medium grade tin slags	Pre concentration (sizing, gravity separation)	*Pyrometallurgy*
40-100	Alloys, scraps		*Chlorination*
20-40	Natural ores	Floatation, leaching, magnetic, electro-static separation. Primary concentration classifications, stage treatment	*Hydrometallurgy*
20-40	Synthetic concentrates		
> 15	*High grade tin slags*		

Table 2 displays the beneficiation route and chemical extraction route suitable for different grades of tantalite ore assay. The very low-grade deposit (2-10%) is preferably beneficiated through preconcentration and pyrometallurgy technology. The concentrate in alloys and scraps containing between 40-100% primary metal are best recovered through chlorination. The natural tantalite ores, synthetic concentrates and high grade tin slags are best beneficiated through flotation, leaching, magnetic separation, electrostatic separation, classifications etc. deploying the hydrometallurgy technology.

The tantalite ore reserves investigated by [16] had 38.87% tantalite ore concentrate except for the Otu deposit (see Table 1) which had an assay of 8.00% Ta_2O_5. This average tantalite assay in relation to Table 2, implies that the Nigerian tantalite deposits are candidates for hydrometallurgical beneficiation; except for the Otu deposit which needs to be pre concentrated to upgrade the ore to assay grade suitable for hydrometallurgical beneficiation.

The conventional method for the beneficiation of tantalite mineral is the gravity separation technique [18-19] due to the density of Ta – Nb minerals which allows concentration with other heavy metals. However, in the present effort, the focus is the concentration of multi-constituents of tantalum bearing minerals with a view to generating economic value for the secondary ore concentrates in the tantalum bearing minerals.

Our beneficiation effort proposed a model that combines the traditional gravity method of beneficiation of tantalite and niobium minerals with techniques that are capable of equally beneficiating TiO_2, MnO_2 and Fe_2O_3 as adjunct recovered concentrates.

A scheme of the proposed model is presented in Figure 3. The figure incorporates mainly gravity, magnetic and electrostatic separation techniques with leaching as adjunct beneficiation technique to generate the various secondary ore concentrates.

In the proposed model, as-mined tantalite ore is crushed, ground and sieved to 125 micron size in appropriate system. The screened ore is subjected to gravity separation technique where Ta_2O_5 / Nb_2O_5 and other associated minerals are concentrated. The Ta_2O_5 / Nb_2O_5 is separated from associated heavy metals such as wolframite, ilmenite which are electrically conducting through electrostatic separation.

The other heavy metals such as hematite, manganese oxide and rutile are roasted, dried and subsequently subjected to magnetic separation where the hematite transformed to ferromagnetic magnetite is concentrated from paramagnetic manganese and titanium ore minerals. The titanium/manganese ore are subsequently beneficiated through hydrometallurgy using leaching. This based on the work of Adetunji et al [16] in terms of labour cost and simplicity of the process is best facilitated by direct dissolution in hydrogen fluoride (HF).

The effectiveness of the model is to be evaluated by optimizing the dissolution of the important metallic ore concentrates through the analysis of the chemical equilibria parameter. The result of this analysis will be a basis for the design and development of a pilot multi-constituent tantalite ore beneficiation technology.

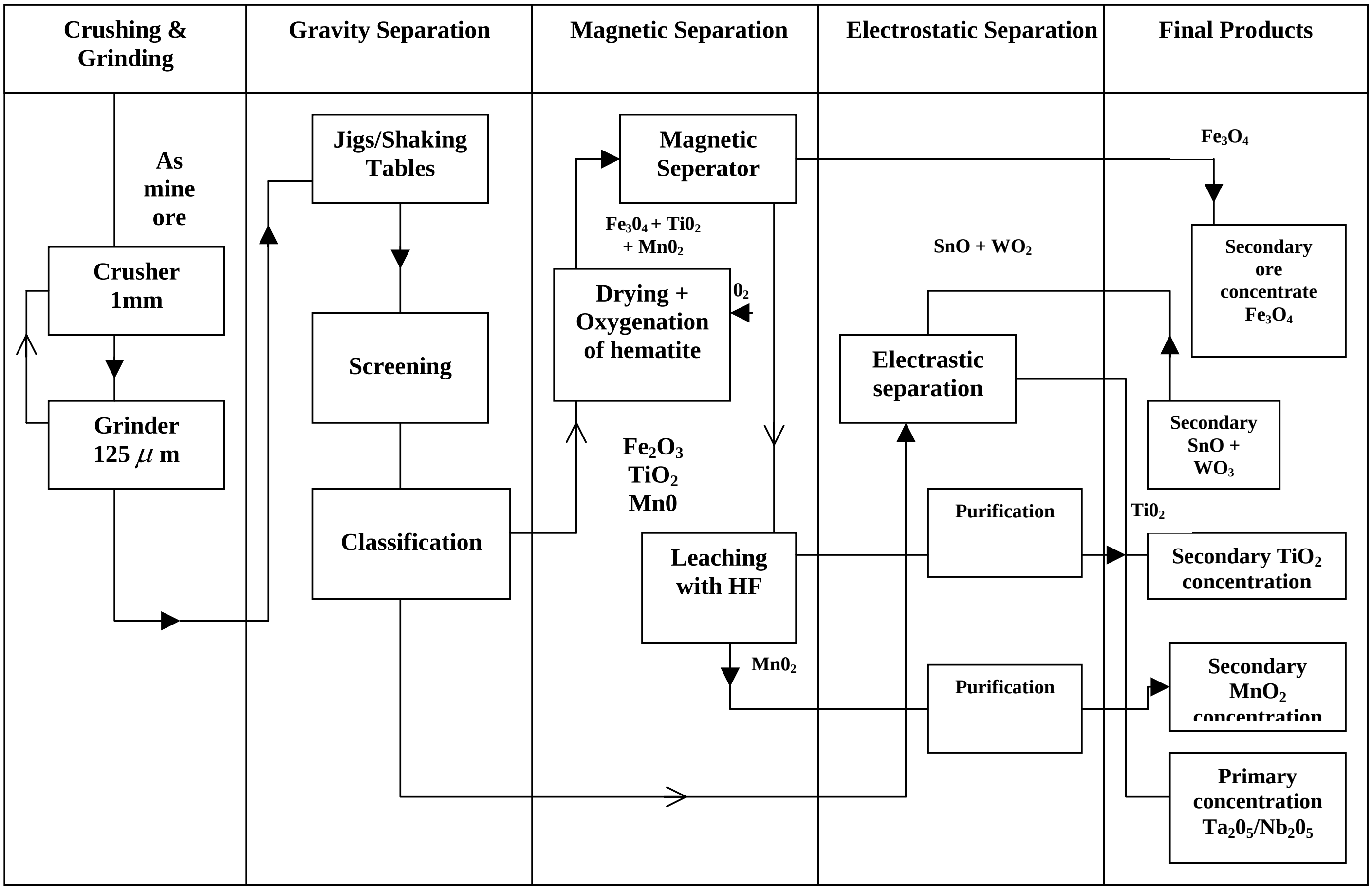

Figure 3: Proposed Multi-Ore Constituent Concentration Model

CONCLUSION

Previous studies on the Nigerian tantalite deposits had revealed that the deposits contains other important constituents other than the Ta_2O_5 and Nb_2O_5 ore concentrates in appreciable proportion that can stimulate secondary recovery process. These important constituents are TiO_2, MnO_2 and Fe_2O_3. The present work reviewed the conventional beneficiation routes vis-à-vis the mineralogical characterization of Nigerian tantalite deposits and that the hydrometallurgical route is the most economically feasible option.

A scheme has been proposed for multi-ore beneficiation to generate secondary ore concentrates from the primary tantalite beneficiation process. The scheme incorporates combined gravity, magnetic and electrostatic separation techniques. The effectiveness of the model is to be evaluated by optimizing the dissolution of the important metallic ore concentrates through the analysis of the chemical equilibria parameter. The result of this analysis will be a basis for the design and development of a pilot multi-constituent tantalite ore beneficiation technology

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