Sustainable extraction of multi-mineralised base metal deposits: A case study of a copper deposit in Namibia

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INTRODUCTION

The vision of the Namibian mining industry is "to be a widely respected, as a safe, environmentally responsible, globally competitive, and meaningful contributor to the long-term prosperity of Namibia"[1]. In order to realise this vision, the mining industry is expected to ensure responsible mining and processing of ores while contributing to the gross domestic product (GDP) of the country in the immediate and long term. Socio-economic benefits in the long term can only be realised if the mineral reserves are accurately characterised and quantified to inform the development of optimal process flow sheets for the metal extraction. Namibia is endowed with deposits of various base metals. These include copper (Cu), lead (Pb), zinc (Zn), and tin (Sn). Additionally, Namibia also possesses deposits of energy minerals, namely uranium (U) and lithium (Li) as well as deposits of non-metals such as graphite and fluorspar. The base metal ores are currently mined and processed at various mines in the country, with Pb and Zn mined at Trevali's Rosh Pinah Zinc Corporation (RPZC) while Sn is mined at Afritin Mining's Uis Tin Mine.

Trigon Metal's Kombat Copper Mine which resumed operations in 2021 was the only operating copper mine in the country before it was placed on care and maintenance again in August 2022 after seven months of operation. Prior to resumption of mining operations in 2021, Kombat Mine had been dormant for close to two decades. The other three copper mines, namely Otjihase, Matchless and Tschudi are also on 'care and maintenance'. While the market conditions, especially the copper price, significantly impact the decision to keep the mine in operation, another factor which can force the mine management and investors to cease operation is the significant change in the mineralisation of the orebody. This could result in high operating costs as a result of retrofitting additional sections or simply use of expensive reagents or 'aggressive' operating conditions which are, for example, necessitating the use of additional power or water in the processing plant. The need for an advanced mining method e.g., underground method versus opencast method may also be a critical factor. In short, the sustainability of a multi-mineralised mine can be negatively affected if no appropriate flow sheet development consideration is executed timeously.

[1]Chamber of Mines (2021), 2021 Annual Review Report. Retrieved from https://chamberofmines.org.na/wp-content/uploads/2022/04/2021-Chamber-of-Mines-Annual-Review.pdf

[2]Pitiya, R.P. & Peter, L.J. (2021) A Review on the Deposit Geology and Mineralization Mechanism of Tsumeb Polymetallic Deposit, Namibia. Open Access Library Journal, 8: e8121. https://doi.org/10.4236/oalib.1108121

A good example of an orebody with distinct mineralisation is a copper deposit located within the Damara orogenic belt, approximately 20 km west of Tsumeb in northern Namibia. This copper deposit is mainly made up of sandstone and it consists of three mineralisation zones: the oxide zone outcropping on the surface, a transition (mixed) zone in the middle, and the sulphide zone at the bottom[2]. Copper mineralisation in the oxide zone extends approximately 70 m below the surface; it is mainly composed of copper minerals such as malachite ($Cu_2CO_3(OH)_2$), azurite ($Cu_3(CO_3)_2(OH)_2$), cuprite (Cu_2O), and minor chalcocite (Cu_2S). This mineralisation is disseminated through a sandstone and a conglomerate unit lying above a dolomite unit. The transition zone contains a combination of oxides (predominantly malachite) and the sulphides (predominantly chalcocite and bornite, with covellite (CuS) in minor quantities). While the sulphide zone contains chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), and chalcocite (Cu_2S).

Since the processing plant is usually constructed for a specific ore type (e.g., oxide or sulphide), upon depletion of the oxide ore, the mine has two options which are dependent on the prevailing and projected market conditions as well as financial position of the company. The first option is to cease operation and declare the end of life of mine (LOM). Alternatively, the mine can engage in an expansion programme to develop or re-design the process flow sheet for treating other different mineralisation zones. A holistic consideration of the multi-mineralised zones ensures that the processing plant is designed, in phases i.e., phase 1 and 2, to extract copper sustainably and efficiently from all the distinct ore mineralisation zones. For the copper deposit with three mineralisation zones as discussed above, phase 1 would entail processing of the ore extracted from the oxide zone which responds favourably to the low-cost heap leaching with dilute sulphuric acid (H_2SO_4). The copper sulphide minerals do not respond favourably to leaching unless it is done under reducing and 'aggressive' conditions. An example would be the use of microorganisms in bioleaching or at elevated pressures in autoclaves, i.e., pressure leaching. This should be part of phase 2, in which copper should preferably be extracted from the sulphide ore after a concentration stage such as froth flotation to reduce the tonnage, and thereby improving the grade of metal value while reducing the concentration of impurities (gangue) by using pyrometallurgical unit processes in a smelter, such as at Dundee Precious Metals Tsumeb smelter. Such a processing route is characterised by fast kinetics, but it can be energy-intensive. Depending on the ratio of oxide/sulphide minerals, the transition ore can be processed by using the flow sheet for either oxide (i.e., via heap leaching, at adjusted operating conditions, such as increased lixiviant consumption) or sulphide (i.e., smelting, after froth flotation at controlled operating conditions, such as pressure of oxygen to minimise the copper reporting to the slag phase).

The authors propose a holistic and more sustainable approach for the extraction of multi-mineralised base metal deposits in order to increase the LOM of such operations. The ore from all three mineralisation zones should be extracted as compared to only mining and processing ore from a single mineralisation zone and then closing the mine. The principal aim is to minimise disruption to operations caused by focusing only on specific ore types within a given deposit while knowing very well that the orebody is multi-mineralised. During phase 1, i.e., when processing the oxide ore, a comprehensive metallurgical test work programme should be initiated and fully undertaken to guide the development of the flow sheets for the transition and sulphide ores, with the configuration and/or design of the processing plant pursued towards the end of phase 1 to avoid disruptions to operations after that phase. The alternative is to prolong the LOM after phase 1 by converting the mine into a concentrator to produce the copper concentrate, from both the transition and sulphide ores, which can then be sold to the smelters.

METHODOLOGY

Representative samples for the oxide, transition and sulphide ores were initially homogenised by using the coning and quartering method. They were then crushed by using a laboratory jaw crusher to -3.35 mm. They were further blended and divided by using a riffle splitter and a rotary splitter. The head subsamples were subjected to chemical analysis by utilising the benchtop X-ray fluorescence (XRF) model NEX CG supplied by Applied Rigaku Technologies from Austin, Texas, USA. Thereafter, grindability experiments were conducted by utilising a 305 × 305 mm laboratory ball mill with 19 mm steel balls at a 75% of the critical speed of 112 rpm. The preliminary flotation test work was conducted with the transition and sulphide ores. The flotation experiments were conducted as part of phase 2 of flow sheet development, as discussed above. This is because this copper mine with a multi-mineralised deposit is currently applying heap leaching, which is favourable for treating the oxide ore. The flotation experiment campaign investigated the effect of various flotation process variables such as pH, collector type and dosage, depressant dosage and sulphidiser dosage (in the case of the transition ore). The flotation products were XRF assayed for copper and gangue elements. They were also mineralogically examined by using a JEOL JSM-IT300 scanning electron microscope (SEM) coupled with the Thermo Scientific NS7 energy dispersive spectroscopy (EDS) software supplied by Advancedlab from Switzerland. Finally, the processing routes for various types of copper ores, i.e., oxide, transition, and sulphide, were reviewed to conceptualise the flow sheets for the copper ores based on their mineralogy, chemical composition, and flotation results.

SUMMARY OF RESULTS

Head samples characterisation results

The XRF assays for the head samples are shown in Table 1. As expected, the sulphide ore has a higher sulphur (S) content of 1.15%, the transition ore has a sulphur content of 0.16%, and no sulphur was reported in the oxide ore. Another major difference is the calcium (Ca) content, which is significantly high at 1.72% in the transition ore compared to 0.33% and 0.24% in the oxide and sulphide ores, respectively. The silicon (Si) content is similar in all three ore zones, with the average being 31.62%.

Table 1. XRF analysis for the composite head samples

Ore type	Elemental compositions (%)					
	Cu	Fe	S	Si	Ca	Other
Oxide	1.27	0.89	-	32.33	0.33	65.18
Transition	1.59	2.68	0.16	30.34	1.72	63.51
Sulphide	1.13	1.44	1.15	32.19	0.24	63.85

Flotation results

Flotation of the sulphide ore, containing chalcopyrite as the main copper mineral, can be performed using 200 g/t of potassium amyl xanthate (PAX) as a collector at a pH of around 11. Further optimisation of the grind size, reagents (collector and depressants), and operating conditions (such as airflow rate, slurry density, pH, and redox potential) must be undertaken to reduce the mass pull, which is currently ranging between 60 and 80% (w/w) while ensuring high Cu recovery with the gangue minerals remaining in the tailings.

A sulphidiser, sodium sulphide (Na_2S) was applied to the transition ore at 50, 100, and 150 g/t while keeping the collector (i.e., PAX) concentration at 200 g/t, without adjusting the pH, to determine the effect of the sulphidiser. A high recovery of copper (80%) was obtained with 100 g/t of Na_2S at the natural pulp pH of about 8. Increasing the pH to 11 by using slaked lime or calcium hydroxide ($Ca(OH)_2$) and keeping other conditions the same resulted in a total copper recovery of 92%.

The use of dithiophosphate (DTP) as a secondary collector with PAX yielded a copper recovery of 94% after 30 seconds compared to 47% copper recovery when only PAX was used. There is thus some scope for optimisation studies on the most suitable reagent suite. Regrinding of the middlings (scavenger concentrate and cleaner tailings) must be investigated to further liberate the valuable minerals from the gangue matrix and thus maximise copper recovery.

Conceptualisation of processing routes

The flow sheets which can be adopted for processing of oxide, transition and sulphide copper ores are conceptualised. The techno-economic implications of the flow sheets are discussed. Benefits of the proposed approach are also discussed.

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I am a Metallurgical/Process Engineer with six (6) years of experience. I have worked in the Namibian mining industry at Skorpion Zinc Mine and at Tschudi Copper Mine as a Metallurgist-in-Training and as a Process Engineer, respectively. Currently, I am working as a Junior Lecturer and Metallurgy Programme Coordinator at the Namibia University of Science and Technology (NUST) in the Department of Mining and Process Engineering (DMPE). In addition to the Bachelor of Engineering (B. Eng.) degree in Metallurgical Engineering, I hold a Master of Engineering (M. Eng.) degree in Industrial Engineering with a thesis focused mainly in Hydrometallurgy and Electrometallurgy to be more specific. My master's thesis is titled: "*Designing a continuous quality improvement framework for improving copper electrowinning current efficiency*". I am currently studying towards a Master of Business Administration (MBA) specializing in Management Strategy at the Namibia Business School (NBS), University of Namibia (UNAM). I also hold certificates in project management, strategic business management, business finance and business risk management. I am an associate member of the Southern African Institute of Mining and Metallurgy (SAIMM), and I am registered with the Engineering Council of Namibia (ECN) as a Professional Engineer (Pr. Eng.) specializing in Extractive Metallurgical Engineering.