A BRIEF REVIEW OF OPERATIONS AND WASTE MANAGEMENT PRACTICES OF A POLYMETALLIC UNDERGROUND MINE

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ABSTRACT: *This work delves into the operations and waste management practices of an underground mine located in South Australia. Olympic Dam is a polymetallic deposit discovered in 1975, and its mining operations began in 1988, employing sublevel open stoping for copper-uranium ore extraction. The integrated metallurgical complex technique, including a copper concentrator, solvent extraction circuits, smelter, refinery, and precious metals recovery circuit, maximizes metal production from the mined ore. Waste management practices involve on-site and off-site activities, primarily centered around the tailings storage facility (TSF) and the waste management center. Hence, emerging technologies such as geopolymerization, bioleaching, and the application of bimetallic materials could be explored to treat the mine tailings, aiming to enhance stability, reduce environmental impact, and improve overall tailings management. Collaborative efforts between the mining company, research institutions, and other relevant organizations could be encouraged, as well as pilot projects and field trials for feasibility assessment of the technologies for large-scale operations. The ongoing exploration of these technologies indicates a positive shift toward more sustainable and environmentally friendly tailings management practices.*

Keywords: Olympic Dam, polymetallic, underground mine, wastes, tailings management

1. INTRODUCTION

The scope of mining includes exploration, mine development, operation, decommissioning, and land rehabilitation [1]. Underground and surface (open-pit) mining techniques extract metallic ores from the ground based on the deposit's nature, location, size, depth, and grade [2]. These extracted ores are then being processed to profit and delivered to marketplace or used in technology [3]. Ores cannot be used directly for industrial or commercial purposes; they must be processed into a usable material, such as a specific mineral, metal, alloy, or compound. The transformation involves a coherent sequence of steps [4].

Various engineering studies to extract metals from their ores have been outlined and reported already in many literature [5-14]. Aside from usable materials, managing discardable wastes and tailings has been an important issue. Tailings pose an environmental threat due to the inherent toxic substances but could offer a resource opportunity from potentially valuable residual metals and minerals [15-17]. Treating waste reduces the volume stored on the Earth's surface and its harmful environmental effects; and extracting useful components from waste decreases the need for other mining activities, thus reducing environmental impact [18].

In this work, a brief review of the operations and tailings management practices of a polymetallic underground mine in South Australia, the Olympic Dam Mine, was conducted. This covers ore resources, mining methods, mineral processing, and waste management practices. Emerging technologies for possibly treating the mine tailings for resource extraction & generation and environmental sustainability were also included.

2. MATERIALS AND METHODS

This review considered various reference materials about the Olympic Dam Mine in South Australia. Some published review articles were also consulted [19-21]. Different areas were discussed such as ore resources, mining methods, mineral processing, and waste management practices. Relative to waste management, emerging technologies were also introduced to treat the plant's mine tailings possibly.

3. RESULTS AND DISCUSSION

This section discusses details on the Olympic Dam mine: location, mineral deposits and geology, mining method, mineral processing, on-site and off-site waste management, and technologies for mine tailings treatment.

3.1 Location, Mineral Deposits & Geology

The Olympic Dam polymetallic deposit is 520 km north-northwest (NNW) of Adelaide, South Australia [22]. It is in a significant hydrothermal breccia complex within the Mesoproterozoic Roxby Downs Granite, concealed by 260 meters of overlying Neoproterozoic and Cambrian sedimentary rocks, lacking surface expression. Its discovery was attributed to geophysical data interpretation based on a conceptual geological model [23]. This involved drilling areas with coincident gravity and magnetic anomalies, observed as promising within the framework of an exploration model and analyses of continental tectonics and lineaments [24].

The deposit was discovered in 1975 by the Western Mining Corporation and the production started in 1988 [24,25]. The ore reserves and mineral resources as of the end of 2001 are sufficient [26] making Olympic Dam the world's largest uranium resource and fifth largest copper resource, with additional reserves including approximately 10 million Mt of rare earth elements (mainly La and Ce), 6700 tons of silver, and an average iron grade of about 26% Fe [27].

However, as of June 2011, the mine reported reserves of 146 million Mt with grades of 1.98% Cu, 0.58 kg/t U_3O_8, 0.69 g/t Au, and 4.01 g/t Ag. The probable reserves are estimated at 406 million Mt with grades of 1.79% Cu, 0.57 kg/t U_3O_8, 0.78 g/t Au, and 3.19 g/t Ag. Additionally, measured resources are estimated at 1,408 million Mt with grades of 1.08% Cu, 0.32 kg/t U_3O_8, 0.34 g/t Au, and 2.07 g/t Ag, while indicated resources stand at 4,571 million Mt with grades of 0.88% Cu, 0.28 kg/t U_3O_8, 0.34 g/t Au, and 1.56 g/t Ag [28].

Government Regulations

The South Australian government plays a crucial role in responsible mineral exploration, emphasizing the state's ownership of mineral resources. The Mining Act of 1971 and its regulations govern mineral exploration involving the search for valuable deposits, & overseeing exploration titles, as well as on-ground exploration activities such as environmental management and land rehabilitation. The Minerals Resources Division within the Department for Energy and Mining administers and regulates these processes, underscoring the importance of explorers' compliance with rules and regulations when applying for mineral exploration licenses in South Australia [29].

3.2 Mining Method

Olympic Dam is currently involved with an underground mining operation employing a sublevel open-stopping method [25]. This method is also known as underground hard-rock mining [30]; and is used to excavate hard minerals/ores containing metals [31] such as gold, silver, iron, copper, zinc, nickel, tin, and lead [30]. The underground mine includes over 450 kilometers of underground roads and tunnels [32].

In particular, the orebody is accessed through three vertical shafts and a decline. Each stope, located along the stope center line, may hold up to 300,000 tons of ore, with drilling drives utilized for vertical ring blast hole drilling, charged with ANFO, and detonated using shock tube detonators. The drilling fleet includes production rigs from Atlas Copco and Tamrock, and for development activities, two Tamrock jumbos (now Sandvik) are employed. Additionally, two adapted Simba H4356S production drilling rigs have been provided by Atlas Copco. Moreover, cement aggregate, which is composed of crushed waste rock ('mullock'), deslimed mill tailings, cement, and pulverized fuel ash (PFA), is used to backfill stopes [28].

Ore Handling

Underground mined copper-uranium ore is transported using an automated train and trucking network to underground crushing, storage, and ore-hoisting facilities [32-33]. The implementation of automation, including the haulage system and the 'smart' loader, a robotics-driven ore carrier with decision-making capabilities, has significantly contributed to reducing production costs [28].

3.3 Mineral Processing

In general, an integrated metallurgical complex processing is facilitated that includes a copper concentrator, solvent extraction circuits for copper and uranium, a copper smelter, a refinery, and a precious metals recovery circuit [28, 32-35]. Fig. 4 below shows the Olympic Dam processing plant.

Crushing

Before the metallurgical processing, the copper-uranium ore undergoes crushing [32] through a primary crusher capable of crushing up to 2,200 Mt per hour. Following crushing, the ore is transported to ore bins through an apron feeder and conveyor belt. Subsequently, vibrating feeders draw the ore from the bins and transfer it to two conveyor belts, facilitating transport to the loading pocket of shafts, where it is hoisted to the surface [35].

Grinding

The crushed ore is transferred from the shafts to overland conveyors which transport it to the stockpile adjacent to the concentrator plant. The ore then is mixed with water and autogenous grinding (AG) is facilitated to create a slurry. Vibrating screens and hydrocyclones recycle the oversized particles for further grinding whereas the product from the cyclone overflow goes to for flotation process [35].

Processing

In general, the existing operation uses a concentrator, smelter, and refinery for the production of copper cathode, gold, and silver. The incorporation of the hydrometallurgical operation recovers uranium and facilitates additional recovery of copper. Herein, the entire process is promoted to maximize the metal production from the mined ore [35].

The primary recovery of the high-purity copper cathode is by smelting and electro-refining the high-quality quality copper concentrate from the flotation process of copper-rich sulfide minerals. Wastes produced during electro-refining undergo treatment to extract gold and silver. Following flotation treatment, the fine ore material is leached with sulphuric acid to dissolve uranium and any remaining copper. The resulting leach liquor is processed in a solvent extraction plant to separate the residual copper and uranium streams. Copper, in this case, is recovered through electrowinning whereas the uranium is converted to yellowcake and calcined uranium oxide. The introduction of two pulsed columns enhanced uranium recovery from the solution to approximately 97%. These columns employ air pulses to facilitate the mixing of acidic and organic solutions, improving the contact for the chemical reaction responsible for transferring uranium between the solutions [28, 35].

3.4 On-site Waste Management

Waste management practices at Olympic Dam, encompassing both solid and liquid waste streams, can be described in detail by its on-site and off-site regular activities. Olympic Dam has two principal waste management facilities, namely, the tailings storage facility (TSF) and the waste management center indicating the current positioning of this waste management infrastructure [35].

Tailings Retention System

In South Australia, the management of tailings and tailings storage facilities is focused on the security, stability, and economic viability of the storage of mineral wastes generated from mining and ore processing operations, emphasizing safety and responsibility [36].

Tailings are the byproducts of metallurgical operations, comprising a slurry of fine particles and acidic liquor from which valuable minerals have been extracted [35-36]. The slurry is subsequently pumped to the Tailings Storage Facility (TSF), where the solids settle, and the liquor is reclaimed and directed to evaporation ponds. TSF is of four cells, each covering about 400 ha. On the other hand, five evaporation ponds, each lined with high-density polyethylene (HDPE) and covering an area of approximately 133 hectares, are utilized for evaporating the excess tailings liquor [35].

Approximately eight million tons of solids and 8.5-9 gigaliters of liquor are annually disposed of to the TSF. The hydrometallurgical slurry from the plant undergoes thickening to about 55% solids and desliming to remove sand-sized particles for the production of cemented aggregate filler (CAF) used in backfilling mined-out stopes. Around 400,000 tons of tailings per annum are utilized in CAF manufacturing. Processing wastes, including acidic effluent from the acid plant, are added before pumping to the TSF, resulting in a reduction of pumped tailings to about 47% solids. The tailings are deposited in thin layers in the TSF to facilitate evaporation, reduce seepage, and promote consolidation [35].

Free liquor produced during settling is gathered in ponds at the center of each TSF cell and transferred to one of four evaporation ponds to reduce volume through evaporation. A portion of the liquor (approximately 1.2-3.1 megaliters per day) is recycled to metallurgical operations, regulating tailings density in the deslimes circuit and in the hydrometallurgical process for the recovery of dissolved metals concentrated in the liquor, as a result of evaporation [35].

Some hazardous materials, such as process spillage material and low-level radioactive wastes like personal protective equipment used in uranium packing shed and laboratory wastes produced on-site, are discharged in the TSF. The authorization for the disposal of bulk hazardous waste in the TSF is managed through coordination between the Hazardous Materials Coordinator and the Environmental and Radiation Department, with the process audited by the Radiation Protection Division of the South Australian Environment Protection Authority [35].

Waste Management Center

The waste management center at Olympic Dam is handling about 4,420 tons of general waste annually, utilizing a general solids landfill for about 66% of the waste disposal. The facility also includes a waste transfer station that diverts around 32% of general waste for recycling, while the remaining 2% is stockpiled for future recycling or reuse opportunities. Landfill waste is covered with clean fill from diverse earthworks activities and subsequently compacted. To mitigate water infiltration and leachate generation, sections of the landfill are capped with clay, establishing a low permeability seal [35].

Meanwhile, bulk materials like large scrap metal and concrete are disposed of in a distinct area separate from the general solids landfill due to their size and strength, which can complicate compaction and consolidation. Some hazardous wastes, including cyanide bags and boxes, are transported off-site for disposal in licensed facilities. Bulk solvent containers undergo washing, with the options for reuse on-site, sale off-site, or compaction and on-site disposal considered as the last option [35].

Sewage Disposal Facilities

Sewage and greywater from the site undergo screening and are directed to two sewage treatment ponds located north of the operation. In these unlined ponds, water evaporation occurs, and solids settle, with the pond capacity currently not needing the removal of solids. The disposal rate to this system ranges approximately from 0.2 to 0.3 megaliters per day [35].

Miscellaneous Liquid Wastes

Stormwater runoff from the vicinity surrounding the metallurgical plant is directed to one of several unlined tertiary containment ponds, before being reclaimed to the concentrator. Caustic liquors deemed unsuitable for deposition in the TSF are retained in the caustic disposal pond for evaporation. Waste oil undergoes temporary storage at the waste oil storage facility before being transported off-site for treatment and reuse [35].

3.5 Off-site Waste Management

Domestic Waste

Roxby Downs residents and local industry produce around 1,400 tons of domestic waste annually, collected and managed by the Roxby Downs Council in a local landfill facility. Additionally, activities in the heavy industrial area at Olympic Dam Village and Olympic Village contribute around 100 tons of waste per year, which is likewise disposed of in the landfill [35].

Sewage Disposal Facilities

The wastewater treatment system comprises a sequence of clay-lined lagoons, encompassing three primary, two secondary, two storage, and one final lagoon. This system handles sewage waste from Roxby Downs and Roxby Village, with the capability to receive stormwater flows during intense rainfall events. Following treatment and chlorination, the effluent is directed to reclaimed waste storage tanks, and reuse purposes such as irrigation on the golf course, public ovals, and gardens. The Roxby Downs Council manages this facility [35].

Moreover, the BHP Billiton oversees a sewage treatment system involving screening and lagooning for the sewage from Olympic Village and certain businesses in the heavy industrial area. Other businesses in the area independently handle their sewage wastes within their respective allotments [35].

3.6 Emerging Technologies for Mine Tailings Treatment

This work identified three potential technologies for the treatment of the plant's mine tailings. These are geopolymerization, bioremediation and bioleaching & the use of bimetallic technology. Each of this promotes resource extraction and generation, and environmental sustainability.

Geopolymerization

Geopolymers are aluminosilicate materials characterized by 3D amorphous microstructure, formed by geopolymerization processes, where silicon and aluminum oxide minerals or aluminosilicate minerals are activated by alkalis to create 3D polymeric chains [37]. Geopolymerization is a comprehensive procedure for creating geopolymers, encompassing leaching, diffusion, reorientation, polymerization, and condensation [38].

Geopolymerization are still applied even up to this day as evident in many studies [39-45]. Geopolymerization transforms tailings into geopolymer, a cement-like material. This process stabilizes the tailings, creating a material that can be used for construction. Geopolymerization has the following benefits in treating mine tailings: reuse of mine tailings, stabilization of tailings, tailings valorization, resource efficiency, etc. [39-43]. Construction is still the best possible option to utilize sustainably these tailings and other industrial wastes [39-49].

Bioremediation and Bioleaching

The primary goals of bioleaching include the efficient and cost-effective extraction of metals from ores, minimizing the environmental impact of mining through a natural and sustainable process, recovering metals from low-grade ores economically unfeasible with traditional methods, producing less waste compared to conventional mineral processing, obtaining high-purity metals for diverse industrial applications, and reducing the consumption of energy and resources in the metal extraction process [50]. Bioleaching technology is still emerging even until now as evident in the studies of Pineda et al. [51], Hernandez et al. [52], Zazueta-Álvarezet al. [53], and Kasatkina et al. [54].

Bimetallic Technology

Bimetallic materials consist of two metallic elements arranged in different structural configurations such as core-shell, Janus, and mixed core-shell-Janus. These arrangements result in enhanced reactivity and catalytic properties due to alterations in both electronic and geometric characteristics influenced by each separate monometallic component [55].

The use of bimetallic materials in mine tailings is often geared towards addressing environmental concerns and improving the stability of tailings. Bimetallic materials can be useful in the remediation of contaminants as they have catalytic properties that can promote the degradation of organic pollutants or the reduction of toxic metal ions [56-57]. They may be used to reduce the leaching of toxic metals from mine tailings. The combination of metals with different reactivity can create a barrier that immobilizes certain elements, preventing them from leaching into the surrounding environment [58]. If they have adsorption properties, they can be applied for water treatment in mine tailings. These materials can adsorb contaminants, such as heavy metals, from water, improving water quality and reducing the environmental impact of tailings [59-60].

4. CONCLUSION

Olympic Dam underground mine in South Australia began mining copper-uranium ore employing sublevel open stoping in 1988. The mine uses an integrated metallurgical complex method to maximize metal production and manages waste through on-site and off-site activities, focusing on the tailings storage facility and waste management center. Given the potential of technologies like geopolymerization, bioleaching, and bimetallic applications in mine tailings treatment, the mine should invest further in research and development. Collaborative efforts and pilot projects are essential to accelerate the adoption and assess the feasibility of these technologies on a larger scale.

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