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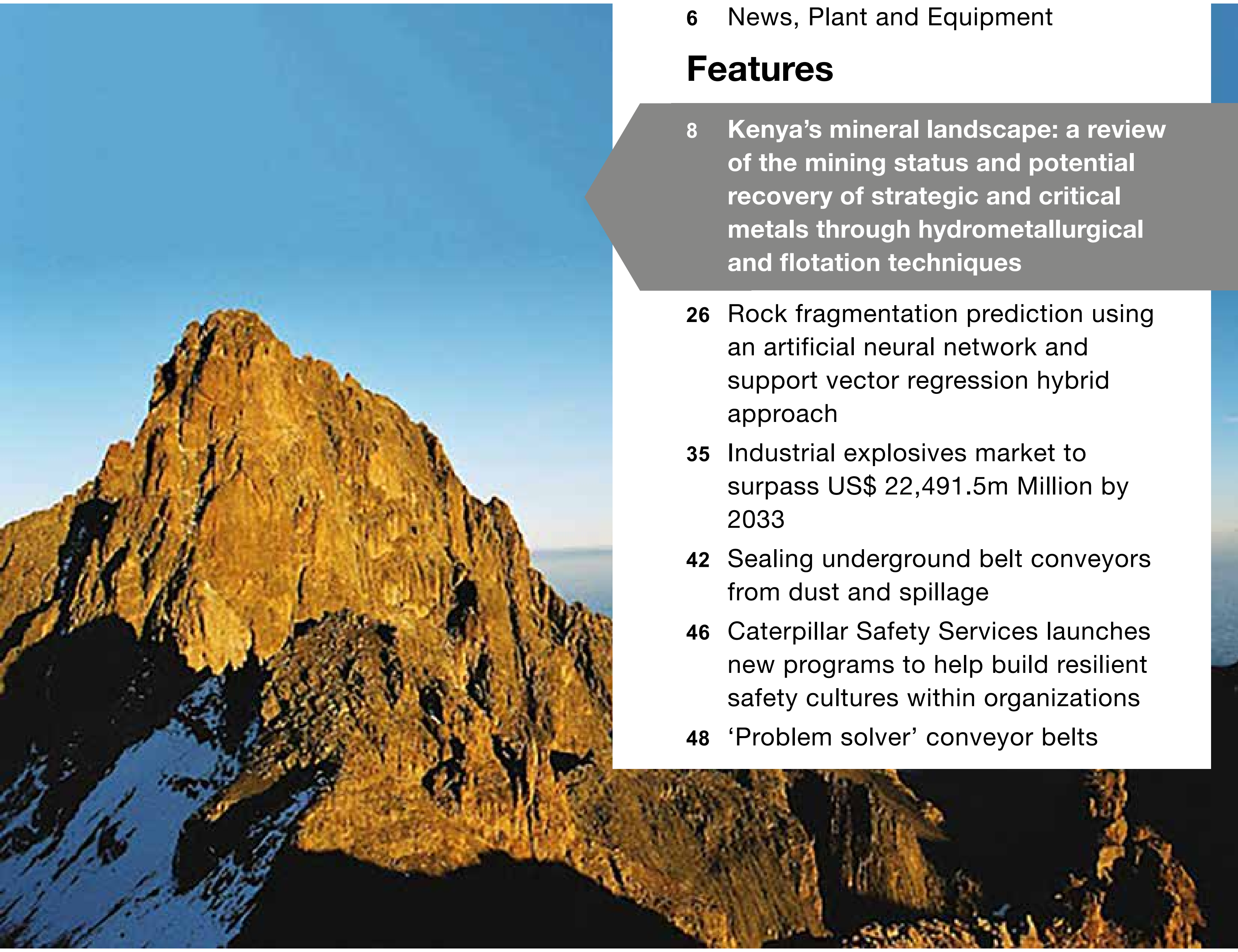
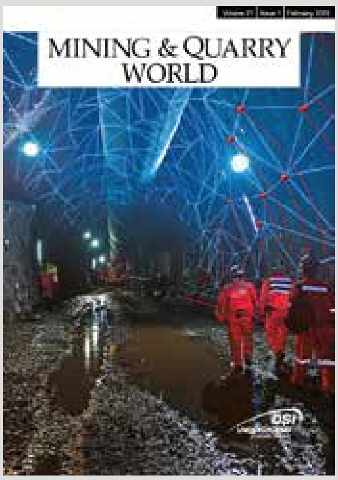
CONTENTS





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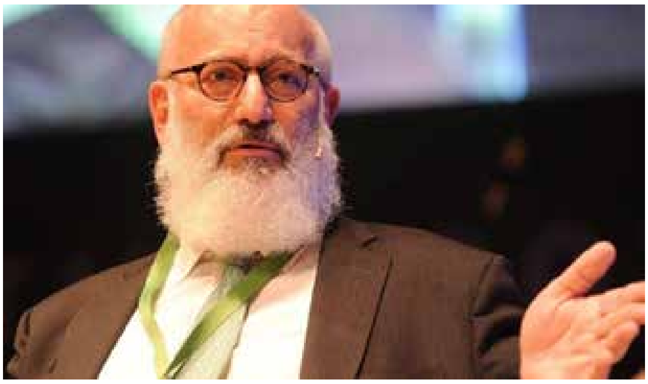
Argentinian entrepreneur Elsztain acquires 5% in Challenger

Argentinian businessman and entrepreneur Eduardo Elsztain has acquired an initial 5% stake in Challenger Gold and has signalled an intention to take a larger stake pending a more detailed due diligence process.

Challenger made a placement of 66.38-million shares at 8.5c a share to an affiliate of Elsztain's group. The placement price represents a 9% premium to the 20-day volume-weighted average price of 7.8c.

Challenger is developing two complementary gold and copper projects in South America, with its flagship being the Hualilan project in Argentina, containing resources of 2.8-million ounces gold-equivalent.

"The investment is a testament to the hard work of our team and the robust potential of our exploration efforts. We look forward to collaborating closely to unlock value for all stakeholders and contribute positively to the local community and economy. This marks a significant milestone in our journey, and we are excited



about the opportunities this partnership will bring," said Challenger executive director Sonia Delgado in a statement.

Proceeds of the placement will be used to accelerate exploration and development activities at the Hualilan project.

Iron-ore's reset lower to $100 heralds China's new economy shift

Iron-ore's reset to around $100 a ton is indicative of a broader reshaping of China's commodities markets that favors the new economy over the old.

The steelmaking material plunged to $95.40 a ton recently, a 10-month low, before nosing back into three figures, testimony to the damage still being wrought by a years-long property crisis that appears far from over. In early January, Singapore futures hit $143.50 a ton, their highest since June 2022.

Iron ore's weakness comes amid tentative signs that the wider economy is beginning to heal. Factory activity snapped a five-month contraction in March, beating estimates and adding to modest signs of recovery.

That divergence between a manufacturing-led upswing and a languishing property market is likely to deepen as Beijing pursues new drivers of growth in sectors like renewable energy and advanced technology. At its peak in 2018, real estate accounted for nearly a quarter of China's economy, according to Bloomberg Economics. Now it's less than a fifth.

Property still makes up the bulk of steel demand. But Beijing has held off on delivering the degree of fiscal stimulus — principally infrastructure spending — that could fully offset the housing crash. Ballooning debt levels at local governments are one obstacle. Meanwhile, the usual lift to construction activity in the spring has also failed to properly materialize, creating uncertainty over when consumption might revive.

All to say, President Xi Jinping's crackdown on property and his drive for "new productive forces" could well herald an era in which iron ore plays a lesser role to the metals set to benefit from the energy transition.

Structural Shift

"It's understandable if the weakness lasts for a week or two," said Cao Ying, chief ferrous metals analyst at SDIC Essence Futures Co. "Any longer than that and the market will start to adjust its expectations as it will look more like a structural shift."

Iron ore can't stay below $100 a ton for too long without higher cost producers shutting up shop. That would thin out supply and put a floor under prices in the near term. But it's the long-term demand side of the equation that's causing most concern. The government in Australia, China's biggest supplier, expects free-on-board prices of $95 a ton this year, $84 next year, and then levels in the $70s out through 2029.

The market's crash contrasts starkly with another commodities bellwether, copper, which is closing in on a yearly high. Supply issues are the immediate driver, but the metal's central role in the energy transition is driving predictions of outsized gains in the years to come. Steel and iron ore markets just won't enjoy the same level of support from that secular shift in commodities consumption.

"There seems to be no end to the real estate crisis, local governments can't sustain current investment levels, consumers are still very cautious," said Tomas Gutierrez, analyst at Kallanish Commodities. There should be a seasonal demand recovery in the second quarter, "but this is not likely to be strong enough to really turn markets around."

Deutsche Bank says Glencore may consider switching listing to US

Glencore may consider switching its primary listing from London to New York, analysts at Deutsche Bank predicted, in what would be one of the most high-profile exits from the UK exchange to date.

Liam Fitzpatrick and colleagues said the UK copper mining and trading firm's primary listing could come into focus due to a lack of shareholder support for a plan to split off its coal business and list it separately in New York.

Mutual-fund data shows the US market is more supportive of companies involved in fossil fuels, with many in Europe excluding the sector from their portfolios, the analysts wrote. Meanwhile, US-listed copper stocks trade at very large premiums to the UK miners, they said.

"UK valuations and coal exclusion could lead to a US listing being considered" by Glencore, they wrote, "We hope the UK remains a key hub for mining investments, but if the valuation gap persists, a shift in listing could make sense."

A spokesman for Glencore declined to comment.

Glencore last year bought a majority stake in Teck Resources' coal business, and plans to put the combined coal operations into a new company listed on the New York Stock Exchange within two years.

Companies raised just $1-billion on the London Stock Exchange in 2023, the least since 2009, as trading volumes slumped. An especially bitter blow was London's failure to secure the listing of one of the UK's most important technology companies – Cambridge, England-based chip designer Arm Holdings.

The MSCI UK share index was trading at a 46% discount to its US counterpart as of late February, based on forward price-to-earnings ratios, increasing the allure of New York over London.

Several European companies have recently shifted to US primary listings, including CRH, Linde and Ferguson, the Deutsche Bank analysts said, while noting that those firms are much more exposed to the US than Glencore. In 2022, rival miner BHP Group switched its main listing to Sydney, ending a dual arrangement with London. Most of the trading in BHP shares was already done in Australia.

Freeport warns copper export ban could cost Indonesia $2bn in lost revenue

Copper miner Freeport Indonesia has warned the Indonesian government that banning exports of copper concentrate in June could lead to a loss of $2-billion in revenues for Jakarta, a company official said.

Indonesia's export ban takes effect from June in an effort to force miners to invest in domestic smelting facilities, thus adding value to their products, boosting earnings from exports.

Freeport Indonesia, controlled by mining giant Freeport McMoran, though the Indonesian government is a majority shareholder, has called for the ban to be relaxed as its Gresik smelter would not be operating at full capacity by June.

"If we can't export, state revenues will drop by around $2-billion, based on current prices," media quoted CEO Tony Wenas as saying in remarks confirmed by a company spokesperson.

The comments followed a meeting with President Joko Widodo, at which he was accompanied by Freeport McMoran's chairman Richard Adkerson and incoming chief executive Kathleen L. Quirk.

Wenas reiterated that construction of the Gresik smelter would be complete by May and start operating the following month, reaching full capacity later in 2024.

A spokesperson for Indonesia's mining ministry declined to comment. The president's office did not immediately respond to a Reuters' request for comment.

Wenas has previously said Freeport Indonesia would have to cut ore production by 40% this year if the government did not delay the ban.

Recently, Indonesian copper miner Amman Mineral Internasional said it was also negotiating with the government to relax the ban since its smelter would not be ready by May, arguing that the government earns tax revenues from Amman as well as Freeport.

Freeport also raised the matter of extending its mining permit during the meeting, Wenas said.

Widodo and Adkerson met last November to discuss a 10% increase in Indonesia's ownership of Freeport Indonesia and a 20-year extension of its mining permit beyond the current expiry date of 2041.

New energy revitalizes China's coal-mining subsidence areas

The former coal mining hub in north China's Shanxi Province, which was once abandoned and shrouded in silence, is now buzzing with machines and workers bracing the cold winds.

The wind power photovoltaic project, known as the "Jinbei coal-mining subsidence area new energy base project," is located at a coal-mining subsidence area of Datong City. Construction of the project started earlier this year and it is set to be put into production by the end of 2025.

The project's total investment stands at about 55 billion yuan (about 7.6 billion U.S. dollars) and it is expected to generate six million kilowatts of electricity.

A coal-mining subsidence area refers to an area where the ground subsides and collapses after the underground coal resources are drained. This can cause the surface to deform and damage buildings, railways, rivers, and wells within the affected area.

Shanxi boasts abundant coal resources, which have been highly profitable for the province. However, years of coal-mining have resulted in large subsidence areas. Statistics show that the area of subsidence caused by coal-mining in Shanxi has reached 3,000 square kilometers.

Wang Peng, an official of the new energy and renewable energy department of the Shanxi Provincial Energy Bureau, said that development of new energy projects in coal-mining subsidence areas can improve the comprehensive utilization rate of energy resources.

He added that these areas are usually located in industrial belts or on the outskirts of cities, making them convenient for the construction of new energy projects and reducing power grid transmission losses.

According to the official, utilization of the abandoned land could not only lower the cost of new facilities, but also benefit local residents.

The development of the Jinbei coal-mining project has created job opportunities for local residents. According to Fan Chao who was in charge of the project, between 50 and 60 employees were hired locally during construction. Upon completion, 80%of the maintenance workers are locals.

So far Shanxi has built photovoltaic power stations in the coal-mining subsidence areas that can collectively generate at least three million kilowatts of electricity.

In fact, new energy projects have been built in coal-mining subsidence areas in many places across China, with provinces such as Shandong and Anhui also housing such projects.

"New energy is the trend of future development. China's continuous construction of new energy projects on coal-mining subsidence areas will kill two birds with one stone, providing new ideas for both wasteland management and new energy development," said Wang.

Rio takes the reins at Ranger

Rio Tinto will take over management of the Ranger uranium rehabilitation project in the Northern Territory from Energy Resources of Australia (ERA).

Under a new management services agreement (MSA), Rio will provide services and advice on the project including rehabilitation studies and work.

As an 86.3% ERA shareholder, Rio said its work will build off the progress already made so far.

"With the signing of this agreement, we are pleased to be able to directly provide more closure and project delivery experience and know-how to this critical task," Rio Tinto Australia chief executive Kellie Parker said.

"We look forward to working in partnership with the Mirarr Traditional Owners and other stakeholders to complete the project."

Efforts to rehabilitate the land have been in planning since the mine opened in 1981 and ERA has tenure and access to the site until January 8 2026.

Ranger operated as a uranium mine for 40 years before closing up in 2021.

"The ERA team has worked incredibly hard and made good progress rehabilitating Ranger," ERA managing director and chief executive officer Brad Welsh said.

"However, as the project moves into a new phase it will benefit from Rio Tinto's global expertise in mine closure.

"We look forward to working with and supporting Rio Tinto on the safe and efficient delivery of this important project."

ERA will continue to directly manage its commitments in Jabiru, corporate and financial affairs, assets and governance, including the Jabiluka mineral lease renewal, which is set to expire in August.

Barminco secures $393 million contract

Regis Resources has awarded Barminco a $393 million three-year contract for services as its Duketon gold project in Western Australia.

The contract commenced on April 1 and includes underground development, production and support services.

Barminco has been providing its services to Regis through development and production works since February 2019.

Perenti (Barminco's parent company) managing director and chief executive officer Mark Norwell said the company is pleased to be continuing its partnership with Regis.

"This award adds Australian based underground earnings to our portfolio, which is aligned with the ongoing delivery of our strategy," he said.

President of contract mining Gabrielle Iwanow said Perenti's people were at the heart of the company's success.

"Their dedication, innovative thinking and highly skilled efforts have again resulted in the award of a significant contract with the third largest Australian gold producer on the ASX, at a great mine that is located right here in WA," Iwanow said.

"We are proud to continue partnering with Regis Resources as we embark on this alliance style contract to further deliver on our purpose of creating enduring value and certainty."

Firefly raises A$52m for Canada project

Canada-focused FireFly Metals has announced A$52-million in funding to accelerate resource growth at its Green Bay copper and gold project, in Newfoundland.

The Australia-listed company unveiled a share placement of 81.5-million shares at A$0.64 each to institutional, professional and sophisticated investors.

"We decided to raise such a substantial sum in light of the exceptional drilling results we have been generating and the increasingly obvious scope to grow the resource quickly by extending the known mineralisation and testing the compelling targets nearby," said MD Steve Parsons.

"The result is a game-changing event for FireFly. We are now fully funded for the next 18 months, during which time we will have two underground rigs and one surface rig working flat out to grow the resource."

The drill programme will grow from the original planned 40 000 m to an expanded 100 000 m of drilling that will underpin additional resource growth at the Green Bay project.

50m Michigan grant for Highland's Copperwood project

The Michigan state government has granted Vancouver-based Highland Copper a performance-based grant totalling $50-million for its Copperwood project.

This follows an evaluation of the project's potential and its significance in revitalising the Upper Peninsula, which has faced economic challenges owing to industry closures in recent decades.

The grant, sourced from the Strategic Site Readiness Programme under the Strategic Outreach and Attraction Reserve Fund, aims to facilitate investment-ready sites and bolster economic development.

Funds will be disbursed as performance-based reimbursements, primarily focusing on infrastructure development, including roads, communications infrastructure, and power supply to the site.

Highland Copper CEO Barry O'Shea expressed appreciation for the grant, highlighting its importance as a significant financial boost for the Copperwood project's success and the region's economic strength.

According to a 2023 feasibility study, Copperwood will produce a yearly average of 64.6-million pounds of copper and 106 966 oz of silver over a ten year mine life.

Initial capital expenditure is estimated to be $391-million. The project has an internal rate of return of 17.6% and a net present value of $168-million, after tax.

Kenya's mineral landscape: a review of the mining status and potential recovery of strategic and critical metals through hydrometallurgical and flotation techniques

Kenya is an East African country with the third-largest economy in sub-Saharan Africa. The demand for metals and minerals continues to increase due to urbanization, population rise, and new infrastructure growth in different countries. Kenya formally confirmed the discovery of oil and various minerals in April 2013, launching itself as a new player in Africa's rapidly expanding extractive sector. This review paper highlights the mining status in Kenya and the role of hydrometallurgical and flotation processes in the recovery of deficit metals from ores and mine wastes. The nation's 2030 Vision is anticipated to benefit greatly from the proceeds from the sale of oil, gas, and valuable metals. Because Kenya was originally mapped as an agricultural region, less mineral prospecting was done in earlier times. The country's mining industry is now dominated by the manufacture of non-metallic goods, and it is largely neglected for minerals. One of the most serious problems for the mining industry in Kenya is the production of tailings that hold strategic metals. The material is already ground, which means the most energy-consuming process has been already applied, and chemical engineering processes like leaching are more feasible at this point. Hydrometallurgical and flotation recovery of valuable metals from wastes, high and low-grade ores, or tailings is essential. The resources will be preserved, which ensures sustainability in the growth of the mining industry.

INTRODUCTION

Mining is the practice of extracting valuable minerals or other geological materials from the Earth's crust, for economic development. These materials can be found in seams, reefs, lodes, orebodies, etc. Sustainable growth satisfies existing demands without jeopardising the capacity of future generations to meet their needs. Justifiable development must be implemented in all human pursuits, and this requires responsible mining. It is no longer possible to extract raw materials just based on economic considerations; social and environmental factors must also be taken into account. As a result, minimal environmental effects, human health safety, full resource utilisation, and waste-free mines should all be goals of good practice standards for mining and processing mineral resources[1]. Mineral-rich nations make use of these resources to shift their economy in the direction of sustainable development. Because of their abundant mineral resources, countries like South Africa, Australia, the United States, China, and Ghana, among others, are now industrialised[2]. The mining industry is anticipated to be the main engine of industrial expansion in low-income countries, particularly in Africa. These African nations include, among others, Kenya, Ghana, South Africa, Mali, and the D.R.C. (Democratic Republic of the Congo). Initiatives such as the Africa Mining Vision (AMV), a "pathway" developed by African states themselves, place the continent's long-term and wide development goals at the center of all policy formulation related to mineral exploitation. It was started to aid in the economic transformation of Africa's mineral-rich regions[3].

Since the Industrial Revolution, the use of energy resources (primarily fossil fuels) has increased dramatically on a global scale[4]. In the coming decades, it is projected that the global energy sector will experience a continuous shift towards renewable energy alternatives[5]. With an expected rise of electricity demand of 150% from the year 2010 to 2050, renewable energy solutions, including photovoltaic power, hydroelectric power, and wind power, are going to play a significant part in satisfying future global demands[6]. The need for key metals will increase substantially as a result of the broad acceptance of technologies with low carbon footprints[5]. As millions of humans adopt contemporary ways of life, the demand for vital metals is, in fact, on the rise[7]. Still, the loss of minerals required for renewable energy technologies could make it more difficult to move from a fossil fuel-based to eco-friendly substitutes. Kenya is one of the ideal places that can contribute strategic and critical metals to the global economic chain. Therefore, this study reviews Kenya's present situation concerning strategic and crucial metals and discusses techniques for recovering them through hydrometallurgical processes. The article also, in its last section, introduces the concept of strategic and critical metal recovery using flotation techniques. Proposals and prospects for the future application of the described technologies in Kenya have also been given.

Strategic and Critical Metals

Strategic metals are resources required for vital use in times of crisis, but their acquisition is uncertain in terms of quality, quantity, and timing and any justification for their supply would require advanced planning[8]. When a metal is essential to the state's economic strategy, which includes its defense, energy, and security strategies, it is also said to be strategic. However, metal could be seen as strategic for a certain business or set of industries, including those in the automobile, renewable energy, aerospace, nuclear, ICT (Information and Communication Technologies), and electronics sectors, and so on. Each region has specific types of metal that have been determined to be crucial and strategically important for their economies. Kenya classified Ti, gas, oil, Cu, diamond, Au, Nb, gypsum, sand, and fluorspar, amongst others, as strategic and critical materials for Vision 2030[8]. However, a region like the United Kingdom outlined Sb, Be, Cr, Au, Hf, In, Co, Ga, Ge, platinum group metals (Pt, Ir, Pd, Os, Rh, Ru, Re), REEs (Rare Earth Elements), Ta, Ti, W, Li, Mg, Ni, Nb, and V as strategic and critical materials.

Critical metals are those that are expensive, difficult to substitute for, geologically rare, prone to potential supply constraints, and required for an economically significant drive. These metals are significant due to their unique features. The possibility of supply restrictions seems to be the most important aspect of these characteristics. Unlike in the 1950s, almost every metal in the periodic table is needed currently to produce different products for society, **Figure 1**. A good percentage of these crucial metals were disregarded and treated as mine waste fifty to sixty years ago[9].

Metals such as REEs, Ge, Ta, Se, Sn, In, Ga, and Te are geologically sparse, though crucial[11]. Relatively low atomic weight La, Ce, Pr, Nd, and Pm are categorised as light REEs (LREEs) while Sm, Tm, Yb, Eu, Dy, Ho, Gd, Tb, Er, and Lu are classified as heavy REEs (HREEs) because of their high atomic weight. Since they are widespread, even though it is rare to locate them in quantities large

Figure 1: A periodic table displaying the aspects of various types ofmetals and their economic status [10].

enough to permit the production of profitable minerals, these elements are referred to as REEs[12]. Due to their occurrence in ore deposits comparable to those of lanthanides and exhibiting the same chemical properties, Y and Sc are likewise classified as REEs[13,14].

When contrasted to the other elements in the periodic table, REEs exhibit distinct magnetic, electrical, optical, luminescent, and chemical properties[15]. Considering that the majority of REEs have similar oxidation states and atomic radii, they can substitute one another in a variety of crystal lattices. Due to this substitutional capacity, numerous REE occurrences can be found in a single mineral, which leads to a widespread distribution of REEs in the Earth's crust. They can be found in a variety of mineral forms, including oxides, carbonates, phosphates, silicates, and halides. Generally, REEs are high on the priority list of essential metals in many nations where these metals are in short supply[13].

MINING SITUATION IN KENYA

Kenya, located in the eastern part of Africa, is richly endowed with different types of mineral resources. The Kenyan government assessed its mineral potential and produced a working document in 1999, and over 400 mineral occurrences were identified. The government introduced regulations to drive this sector[16]. Vision 2030 recognises the such industry as one of the key drivers of the country's economic development. Growth in this sphere is expected to increase the number of jobs, the income of the workers, and the country's GDP (Gross Domestic Product). The 2010 constitution created Counties and gave them the capacity to establish and carry out their development strategies. This new dispensation is forcing Counties to assess their resources and exploit them for their local development. The resources vary from County to County and are highly dependent on the topography, drainage, ecology, and climatic conditions of the County. The worldwide demand for minerals is projected to progressively rise at a mean rate of approximately 3% annually[17]. That is likely to trigger more exploration and mining activities in the resource-endowed regions of the country.

Because Kenya was originally mapped as an agricultural region, less mineral prospecting was done in earlier times. The country's mining industry is now dominated by the manufacture of non-metallic goods, and it is largely neglected for minerals. For instance, Kenya is the world's third-largest supplier of soda ash and ranks seventh in terms of fluorspar production. Additionally, Kenya formally confirmed the discovery of oil and various minerals in April 2013, launching itself as a new player in Africa's rapidly expanding extractive sector[18]. The non-renewable resources mentioned above are, regrettably, mainly found in places with high rates of poverty, ongoing droughts, instability, and long-term marginalisation by the government. Conflicts between local communities, international corporations, and governmental organisations are consequently high[19].

Fe ore, Ti, and Au are amongst the metallic minerals now produced in the country. Kenya's export data show that this industry is constantly expanding. Along with industrial minerals like talc, gypsum, dolomite, and gemstones, Kenya's mineral suite also contains resources like Ag, Cu, and Zn, REEs, coal, limestone, soda ash, Mn ore, fluorspar (CaF_2), diatomite, chromite, Nb, and silica sand. Natural fluorspar (CaF_2), largely mined in Kenya, is typically associated with other minerals such as phosphates (PO_4^{3-}), quartz (SiO_2), celestite ($SrSO_4$), galena (PbS), calcite ($CaCO_3$), barite ($BaSO_4$), and chalcopyrite ($CuFeS_2$)[20]. The most valuable REE resources in the world are also located in the coastal region (Jombo Complex) at Mrima Hills, where Cortec Mining Kenya Limited estimated that they could have an in-ground value of up to USD 62.4 billion[19,21,22]. Mrima Hill is home to a carbonatite cluster. The laterite capping resulting from the weathering of the hill's igneous constituents has economic grades of REE and Nb mineralisation[23].

In terms of Counties, Turkana County has oil, gypsum, graphite, Zr, Nb, Ba, Pb, Fe, Te, Ag, Mn, Cu, and Ni ores, whereas Taita Taveta principally possesses Fe, Mn, Cu, and quartz. While Kwale County is abundant in Zn, Pb, Cu, U, Ti, REEs, Nb, and oil, Kitui County has significant amounts of Fe, coal, Cu, limestone, amethyst, and sapphire. Lamu County is rich in Ti, gas, and oil, whereas Migori County has commercially exploitable deposits of Zn, diamond, Au, Al, Fe, and Cu. Au generation in Migori and other regions is a significant driver of the nation's economic development and growth, contributing approximately USD 10.3 million/year to the country's economy[24]. Transmara and Migori districts began to mine Au in the year 1930. However, industrial mining became significant recently in the country due to the discovery of Au-bearing reefs in the Lolgorien region. The local population and various enterprises that perform mining operations in the area now rely heavily on these activities as one of their main sources of income[25]. **Figure 2** shows some of the minerals that have been confirmed to be available for economic purposes in Kenya.

For the nation to achieve the objectives of Vision 2030, the Fe and steel industry will play a significant role in the industrialisation process[27]. Fe minerals are widely present in western Kenya, especially in Nyanza. Furthermore, there are untapped reserves of Fe ore in various Kenyan Counties, including Taita Taveta (Manyatta), Siaya (Samia), and Taraka (Marimanti). Although complicated, the process of making steel essentially involves melting Fe ore in a blast furnace along with coke. In some rural areas of Kenya and the neighbouring nations, the manufacturing of sponge Fe has been accomplished by smelting Fe ore using charcoal and a forced air draught from bellows made of goatskin. The majority of the ores were first crushed and sent straight to a blast furnace, especially those with 50% or more Fe without beneficiation. To increase the Fe content and get the concentrate ready for the blast furnace, the majority of extracted ores nowadays go through beneficiation[27].

Some of the platinum group metals have also been reported in Kenya. In 14 petrologically distinct spinel peridotite xenoliths found in the Marsabit volcanic zone (Kenya Rift), platinum group metals were identified[28]. However, their concentrations are very low. Marsabit's xenoliths have a total platinum group metals concentration that ranges from 14 to 32 ppb. Unfortunately, such concentrations are too low to be recovered for economic purposes.

Understanding the principles influencing element distribution in the Earth's crust is important. In particular, the role played by rocks and minerals in the uptake of certain metals from groundwaters requires comprehension of the movement and fixation of elements. Scientists have researched the compositions of several hot water springs,

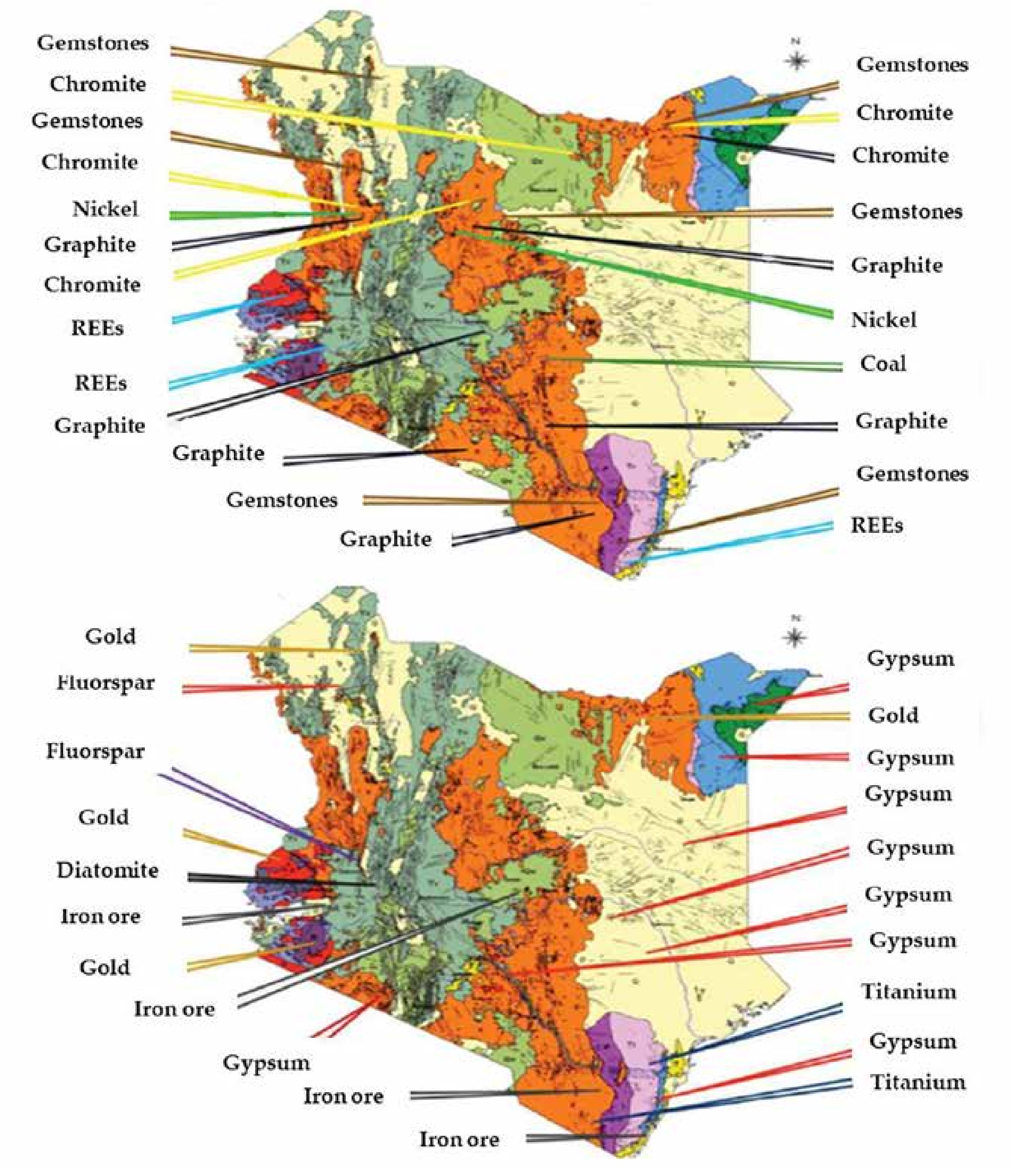


Figure 2: Maps showing mineral occurrence in Kenya [26].

related minerals, rocks, and fossil bones from Kanjera and Kanam near Lake Victoria in Kenya. The location selected for the study was ideal due to the presence of volcanic hot springs and sedimentary deposits connected to Homa Mountain's carbonatite complex, which is comparatively rich in REEs[29]. The findings provided evidence of the absorption and mobility of REEs. Bicarbonate and fluoride were found to be abundant in the spring waters of both locations, and Kanjera's Zr concentration was exceedingly high. All examined rock samples had higher REE contents than chondrites. The rocks further showed higher concentrations of light REEs (Nd, Sm, La, Ce, Eu, and Gd) than heavy REEs (Tb, Yb, Lu, Ho, and Tm). The travertine specimen seemed to be moderately discoloured by Mn and/or Fe2O3 or hydroxide deposits. The acid-insoluble component of the travertine (5.08% by weight) included less than 11% of each REE but more than 60% of the aggregate concentration of some elements, including Cr, Hf, and Ta. The REEs, Th, and U were generally present in fairly large quantities in the carbonate (acid-soluble) fraction. It was notable because such levels were precipitated from percolating ground water. Contrarily, the trona sample only contained detectable levels of the following elements: Ce, Sm, Sc, Cr Eu, Co, and Th. It was concluded that groundwater–rock interaction has a significant impact on rock and mineral composition[29].

Environmental Impacts of Mining Activities

Mining in Kenya and Africa at large is considered one of the main pillars of socioeconomic benefits. However, the same industry is known to be amongst the main sources of pollutants. The influence of mining on environmental contamination can be both geogenic (related to parent rocks) and anthropogenic, encompassing man-made activities such as chemical use[30]. The discovery of mines and their exploitation was solely determined by the economic aspect when the exploitation of natural resources began many years ago. However, tailings production is one of the major issues facing the mining industry. Tailings encompass the remains of the fine-grained (1 to 600 μm) ground rock after the metals of value have been removed from the mined ore[31,32]. Such materials are very reactive, attributable to their minute particle size, with the variation of their chemical and physical properties depending on the ore type. Most of the tailings result during the beneficiation process.

Nearly all the heavy metals in the ores exist as compounds with sulphide in their structures. That contributes to the acid mine drainage (AMD) in the region, responsible for the death of several fish in places like Lake Victoria and the surrounding rivers. AMD is produced when sulphide-containing minerals such as pyrite are exposed to water and oxygen, where oxidation of the minerals results in the generation of hazardous H_2SO_4 acid. AMD is one of the serious environmental challenges associated with the discharge of acidic, metal, and sulphate-containing industrial wastewater into the surroundings[33].

Additionally, wastes produced by mining activities contain elevated concentrations of metalloids and metals. The elements can be mobilised, infiltrating into the surface water and groundwater[34]. A significant fraction of such elements in industrial wastes are nonbiodegradable and highly toxic. Chemical contamination occurs when the reagents added by the mineral processing industries are released. For instance, cyanide or Hg for extracting Au or H_2SO_4 acids used in leaching Cu oxides can be supplemented under controllable conditions but may leak into the environment if not properly handled. Alternatively, chemical pollution can occur when naturally occurring minerals are oxidised[35]. This is mainly predominant when sulphide minerals are involved while extracting Au. Other metals released during artisanal Au mining in regions like Migori and related industries include Cu, Cd, Ni, Zn, Pb, and As, all discharged into soil and water bodies[24].

Kenya is one of the countries in Africa that aims to intensify the extraction of REEs and other metals from various sources. The intricate process of mining resources such as REEs may result in negative effects on the environment and human health. The effects of mining on the environment, nevertheless, rarely receive adequate attention in the majority of developing nations. Deforestation, water contamination, soil erosion, changes in landscape structure, and the destruction of wildlife habitats are a few of the environmental effects of recovering REEs from ore. The effects of REEs are influenced by the type of rock around its deposit, the availability of additional metals or substances within the rocks, the climate, and the distance from streams and lakes to the mine.

Since agricultural land is lost due to the expansion of the mining sites, vegetation in mining areas is also destroyed during ore extraction[36]. Moreover, mine closure results in numerous wastes and the degradation of the land once minerals have been extracted to a considerable extent and the remaining ones are no longer commercially viable for extraction. Information for mitigating potentially hazardous environmental effects following the closure of mining activities and preventing particulate matter emissions from mines should be made available. This is critical, along with the responsible use and disposal of metalbearing technology devices[36]. Furthermore, treatment of tailings and the repurposing of them will be crucial.

The Presence of Critical and Strategic Metals in the Mine Wastes

Valuable metals can be economically recovered from the tailings produced duringmining operations. When selecting the tailings for use in an alternate application, consideration must be granted to the tailings' physical and chemical characteristics[37]. In the dominant geological circumstances within which they are found, the minerals that make up economically valuable ores are largely stable. Their chemical stability decreases when they are exposed to the atmosphere. That explains the high reactivity of tailings. Despite containing 94% of the processed ore, these wastes still contain valuable metals[38]. Thus, from the perspective of protecting the environment and preserving raw materials, continued treatment of these wastes is possible. Additionally, the material has already been pulverised, consuming the high amount of energy in the process; hence, chemical engineering procedures such as leaching become subsequently more practical at this stage[39].

Mine waste deposits are increasingly becoming dependable sources of critical and strategic metals, though some of them could be regarded as low-grade ores based on the current standards[40]. Closing the consumer cycles through the liberation of these metals from complex and dilute waste streams will become significantly viable economically[41]. Access to mine deposits is easy because they are localised at the surface without considerable overburden. The mineralogical composition of the tailings can vary depending on the ores containing the metals of interest. Discarded tailings have been found to contain significant amounts of critical metals such as Ga in bauxite residues or Ge or In in the residues of Zn ores, among others. The processing of the tailings from the ponds and waste-rock heaps of the Penouta mine in Spain led to the recovery of Ta and Nb[42]. However, the crucial influencing factors include the quantities or volumes of the critical raw materials, their concentrations, quality of tailings, and the composition of the minerals in the extractive wastes.

There have been reports of tailings in Kenyan mining industries, including the shortlived Au mine in the Migori district. Both open-cut and subsurface mining techniques were used. After that, the ore was pulverised and panned, leading to huge heaps of tailings and waste rocks. Several elements like Ti, Cr, Rb, Sr, Y, Mn, Zn, As, Au, Pb, Fe, Co, Cu, Zr, and Nb exist in various quantities in the Migori region[25,43]. Such minerals are crucial, and they can be reprocessed for economic gain. For instance, through the application of magnetic separation methods, valuable TiO2 can be extracted from the waste[44].

Western Kenya is another region endowed with minerals such as Au, which was exploited by the British firm known as Rosterman Au Mine industries in the 1930s before they exited the site in 1952. Since the firm's exit, artisan-based miners have been extracting Au deposits from the tailings of the abandoned mines. Alluvial mining is one of the mining techniques used by artisan miners, which encompasses the excavation of the ore from the slow-moving parts of River Isiukhu[45]. The tailings and the gravel of the ore obtained are transported to appropriate locations for processing through panning or sluicing. In the majority of the mining sites, the sluiced tailings are scavenged numerous times before they are ultimately disposed of, to achieve recovery of the Au deposits lost in the previous operations[32].

RECOVERY OF THE STRATEGIC AND CRITICAL METALS FROM VARIOUS SOURCES

The numerous minerals that are already present in Kenya can be recovered using a variety of techniques devised by academics from around the world. For the benefit of the nation, Kenyan researchers and the mining sector can adopt and improve such techniques. Compared to pyrometallurgical methods (roasting, smelting, calcining, and thermal refining of the minerals), hydrometallurgical technologies (leaching, solvent extraction, precipitation, and ion exchange amongst others) offer a greater chance of efficiently recovering very low concentrations of metals with less energy use. Pyrometallurgy has been linked to low metal recoveries, increased air pollution, and huge consumption of energy. Consequently, our review article places a strong emphasis on hydrometallurgy because it is a better alternative.

Leaching

Leaching is one of the crucial steps in the recovery of metals from different materials. However, the process is non-selective; hence, there is a necessity to recover metals from the pregnant solutions using other selective methods like solvent extraction, ion exchange precipitation, etc. The reagents used in the leaching process vary. For extracting base metals such as Cu, chemicals like inorganic acids can be used[46]. These agents are commonly used with oxidants, which enhances the efficiency of the process. For precious metals such as Au, the reagents used are halogens, cyanide, and thiocyanate. Cyanide is the most excellent in the reclamation of precious metals from both secondary and mineral sources[47].

There are various types of leaching approaches, including bioleaching and chemical leaching. Bioleaching is the biological solubilisation of metals from wastes and minerals. That means micro-organisms (for example, *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans*) converting solid, insoluble metals and their compounds into extractable forms. Nonetheless, chemical leaching involves the use of bases/acids, chelating agents, surfactants, redox agents, or salts to liberate the metal from the solid phase to the aqueous phase. Both organic and inorganic acids can be utilised for chemical leaching. EDTA (Ethylenediaminetetraacetic acid) is one of the common chelating agents for various metals.However, NaClO and H_2O_2 are the prominent oxidising agents employed to improve the recovery of the metals from the solid phases[47].

Several technological methods use chemical leaching to process ores (in situ, heap, and dump leaching). The in situ approach involves the application of a lixiviant (H_2SO_4, thiosulphates, thiourea, and cyanides) which is pumped directly into the channels in the rocks or inactive mines. After some time, the resulting pregnant leach solution is pumped to the surface and then taken for post-processing for metal recovery. The technique can be used in the recovery of U and Cu[48]. Contrarily, in heap leaching, the piles are placed in the open air on a previously prepared impermeable pad (plastic, clay). The largest grains are at the base of the pile and the most pulverised at the top.The particle sizes of typical ores range from 10 to 100 mm. The leaching agent is sprinkled on the upper surface of the layer and percolates through it. An aqueous solution with dissolved metals is received through the collecting channel[48]. Similar to this method is dump leaching, except that the ore is taken directly from the mine and stacked without crushing. The method is used for recovering Cu and precious metals and can be applied in extracting low-grade ores[49].

Solvent Extraction of the Common Transition Metals and Uranium

Given its capacity to cope with enormous quantities of diluted pregnant liquor of aqueous solution, solvent extraction is a widely recognised hydrometallurgical procedure. The technique is frequently used in the recovery of leached d-block, REEs, and precious metals using extractants. The extractant is an organic ligand that is intended to coordinate with the cations in a targeted manner[50]. This procedure is mostly accomplished by vigorously agitating the two immiscible media, enabling the solute(s) to be transported from one phase to the other in a controlled manner. Normally, there are two phases involved: an organic phase, having the extractant dissolved in a suitable hydrocarbon diluent; and an acidic aqueous medium, having the target metal ion(s)[51]. The pure extractant is occasionally employed as an organic solvent. However, because of its high viscosity, pure extractants are typically not used. For high product purity and large-scale manufacturing, solvent extraction is a more practical technology that has gained widespread acceptance. The above technique is incredibly practical in hydrometallurgy since it does not require specialised equipment, and it uses inexpensive chemicals to extract metals from their secondary and primary resources[52].

In recent years, there has been an evident expansion in the industrial application of Ni and Co. This may be seen in two ways: the rise of the manufacture of such metals globally, and on the other side, the presence of progressively greater quantities of different wastes containing Co and Ni[51,53-55]. These metals' unique characteristics, such as their exceptionally high melting and boiling temperatures, hardness, thermal conductivity, electrical and changing oxidation states, magnetism, and propensity for forming alloys with additional elements, make their recovery and recycling intriguing at the moment. The isolation of Ni and Co requires high precision due to their comparable physicochemical characteristics. The most important step in the process is selecting an appropriate extractant, which is typically dependent on the acidity and constitution of the leaching mixture[56]. By utilising diverse techniques, researchers have attempted to enhance the solvent extraction approach. An efficient extractant for the separation of Ni and Co was reported to be Cyanex 272 [bis(2,4,4-trimethylpentyl) phosphinic acid]. Cyanex 272 and D2EHPA [Di-(2-Ethyl Hexyl) phosphoric acid] can be used to separate Zn and Mn from Ni in the leach solution. According to the observations, Cyanex 272 and D2EHPA produced a superior separation of Ni and Co[56].

Kenya was ranked as the 10th highest exporter of Nb, Ta, V, and Zr ore worldwide in 2021, with USD 44.1M in exports of these metals[57]. Nb, Ta, V, and Zr ore was rated as Kenya's 29th most exported good that year. Such critical metals can be recovered through hydrometallurgical procedures. In recognition of its exceptional physicochemical properties, V – often referred to as the "vitamin of modern industry – is used extensively in various industries. The two primary categories of V recovery methods are roasting extraction and direct extraction[58]. The extraction of V4+ and Mn^{2+} was explored using new technology for selectively separating and extracting them from a co-leaching mixture of roasted stone coal and pyrolusite via solvent extraction. According to the findings, 99.13% of V4+ was recovered using three counter-current extraction steps with 5% (v/v) EHEHPA (2-ethylhexyl phosphonic acid mono-2-ethylhexyl ester) and an organic/aqueous (O/A) ratio of 1:1 under a starting aqueous pH of 2.0. With three counter-current extraction stages, 99.74% of Mn^{2+} was extracted by applying 40% (*v/v*) D2EHPA with a 60 mol% saponification effectiveness at an O/A phase ratio of 2:1 and a preliminary aqueous pH of 3.5. Following a two-stage counter-current experiment using 1 M H_2SO_4 at a 2:3 O/A phase ratio, Mn^{2+} was found to be completely scrubbed off[59].

A synergistic recovery method for Cu^{2+} and Zn^{2+} ions from chloride aqueous solutions has also been developed. The selective extractant was obtained through a combination of trioctylphosphine oxide (TOPO) and Aliquat 336. Employing 0.06 M Aliquat 336 and 0.025 M TOPO in kerosene, Zn^{2+} ions were effectively separated from Cu^{2+} ions[60]. Equivalent amounts of both phases (10 mL each) were physically mixed for 20 min during the process at a fixed temperature (25 ± 2°C). The mass balance was then used to determine the distribution ratio (D) of the cations measured by an atomic absorption spectrometer, **Equation 1**.

Equation 1:

$$D = \frac{[Me]_{org}}{[Me]_{aq}}$$

Equation 2 gives the extraction percentage *(% E)*,

Equation 2:

$$\% E = \frac{D}{D+1} \times 100$$

where the concentrations of the metal ions in the aqueous and organic media are $[Me]_{aq}$ and $[Me]_{org}$, respectively.

Equation 3:

$$\% E = \frac{D}{D+1} \times 100$$

Equation 3 was used to obtain the selectivity coefficient of metal *M1* over metal *M2*.

Low recovery of Cu^{2+} with TOPO was observed in the 0.1 to 2 M range. However, the extraction efficiency of Zn^{2+} and Cu^{2+} from HCl solutions with Aliquat 336 was reported to be quite high. In HCl solutions containing 0.05 M Aliquat 336, selectivity coefficients of Zn^{2+} over Cu^{2+} were very low. The extraction of Cu^{2+} and Zn^{2+} to the organic phase can be linked to results in the formation of their anionic complexes at greater chloride concentrations. The Cl^- ions' impact increases the development of recoverable anionic compounds such as $ZnCl_3^-$, $ZnCl_4^{2-}$, and $CuCl_4^{2-}$ species in the aqueous phase. That increases the extraction of Zn and Cu. As a result, Aliquat 336 is highly effective at removing these metal ions from the solution. This chemical functions as an anion exchanger. The reaction between the Aliquat 336 extractant (R_4N^+Cl) and the metal can be represented as **Equation 4**[60]:

Equation 4:

$$(MCl_4)^{2-}_{(aq)} + 2R_4NCl_{(org)} \Rightarrow (R_4N)_2(MCl_4)_{(org)} + 2Cl^-$$

The Institute of Nuclear Chemistry and Technology (INCT) in Warsaw, Poland, has also created several technological schemes for recovering strategic metals from different waste materials. The institute examined if Zn, Mn, and Mg could be separated from used Zn electrolytes selectively, **Figure 3**. D2EHPA diluted in n-heptane was used to extract these elements. The separation of the metallic compounds from the SO_4^{2-} mixture having 0.89 g/dm^3 of Mn, 15.9 g/dm^3 of Zn, and 24.3 g/dm^3 of Mg was evaluated. According to the study's findings, both for Zn and Mn, the extraction equilibrium was reached after 4 min, during which pH modulation regulated the extraction's selectivity[10].

Cu floatation tailings have substantial amounts of Cu, plus other toxic elements such as Pb, Zn, U, and Co. The regularly applied methods in the Cu mining industry often result in great losses of the deficit and valuable metals in the streams of their tailings. The formulation and implementation of hydrometallurgical advancements is a solution that is viable for higher efficiency in recovering various elements[61].

A research investigation on the extraction of Cu and other metals was performed by INCT[62]. An O/A ratio of 1:1 was used in the extraction procedure, and the extractant used comprised a combination of benzoic acid (0.5 M), the aromatic solvent toluene, and the aromatic amine p-toluidine (0.25 M). Cu^{2+} ions were removed using an aqueous sulphate solution. With the help of sodium carbonate, the aqueous phase's pH was kept between 3.6 and 3.8. Other metal ions, such as Ni^{2+} and Co^{2+}, could be separated once the Cu ions had been separated. The procedure was carried out by shaking at 25°C in a mechanical shaker. In the majority of cases, distribution equilibrium was reached with a shaking time below 60 min. Ion separation was continued until metal ions were recovered to a degree greater than 99%. The extraction of V, Mo, and U was studied using D2EHPA in toluene. The concentrations considered in the research were 0.3, 0.2, and 0.1 M. The extraction processes took place for 15 min under O/A ratio of 1:1. With 5% Na2CO3, the organic phase was back-extracted for 15 min. A 100% extraction from the pregnant solution was confirmed by a total transfer of Cu into the organic phase. The scholars were able to significantly speed up the analytical work using the radiotracer approach, which was a very helpful research tool. The radiotracer was essential in determining the ideal conditions that produced the highest possible recovery efficiency for Cu. The findings could be utilised as a guide when designing procedures for recovering Cu and other supporting components from flotation tailings after Cu ores have been processed, as shown in **Figure 4**[62]. The scheme represents two options of hydrometallurgical process application: recovery of metals from flotation tailings or low-grade Cu ore.

In recent years, the INCT has also been researching the potential for recovering U and other elements created as waste products during the manufacture of Cu concentrate from Cu ore[61]. The utilisation of the hydrometallurgical processes unlocks the channels for retrieving all the metals present in the liquor. That can be achieved by using a common chemical engineering unit process that is used to recover U and other metals[38]. *In situ* leach (ISL) processes, in addition to underground and open pit mining techniques, are frequently used to extract minerals such as U. A small amount of U can be extracted as a byproduct of processing Au and Cu ores or deposits of phosphate rock.

Research was carried out on the Polish Cu mining industry, with the prospect of recovering U and rare metals from industrial wastes[38]. In the recovery of U, the commonly used method of precipitation was assessed. The hydrometallurgical recovery processes of U encompassed the application of a concentrated U mixture for the production of spherical particles of UO2 by the complex sol–gel process (CSGP), **Figure 5**. The two hydroxyl sets of ascorbic acids were readily present, including the $UO2^{2+}$ that permits the creation of complexes. The study reported that the combination of both extraction and sol–gel processes had a synergistic impact, which resulted in the design of a reliable scheme for the recovery of U from Cu mining tailings and minerals.

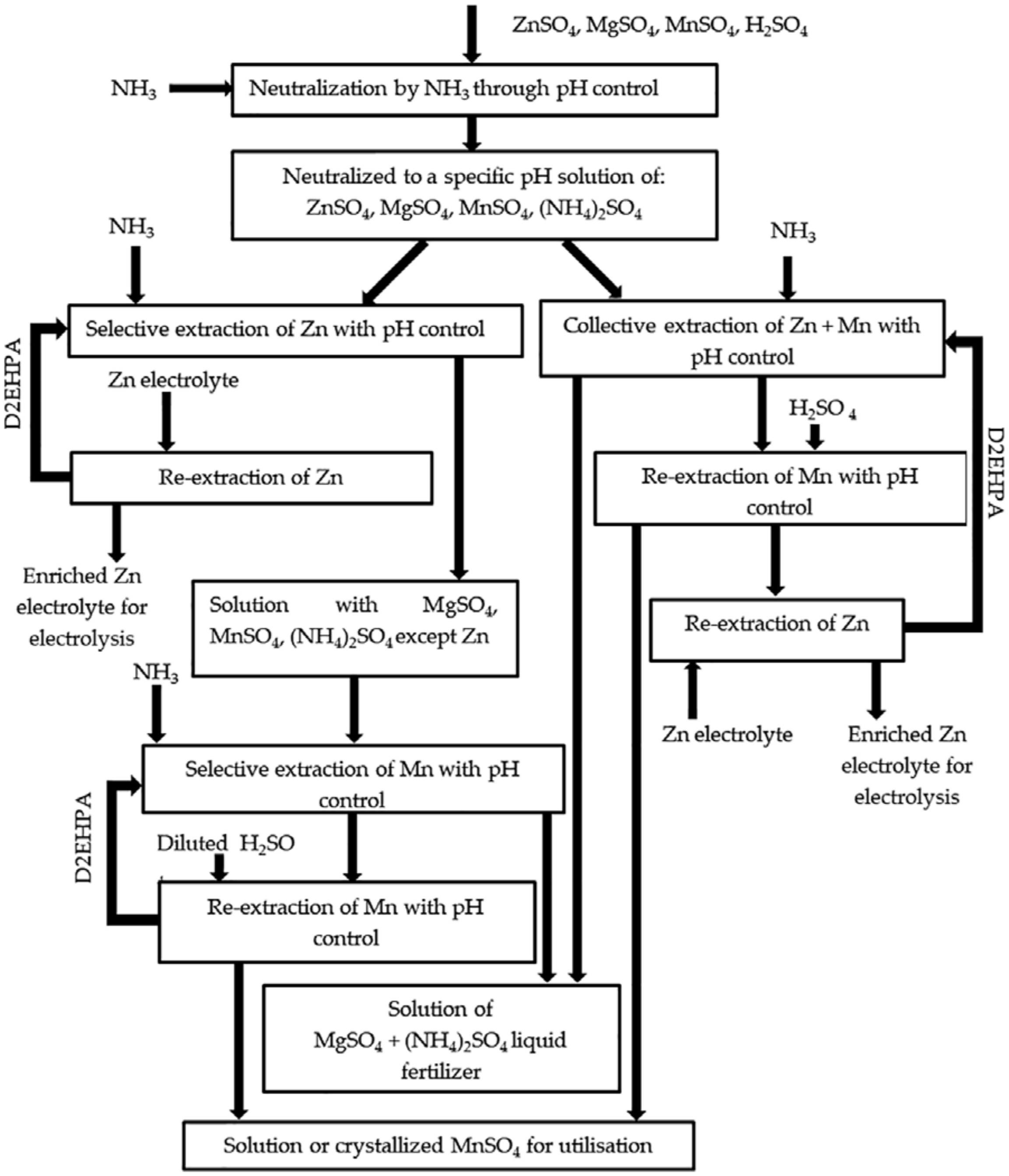


Figure 3: Extraction of Zn from electronic wastes.

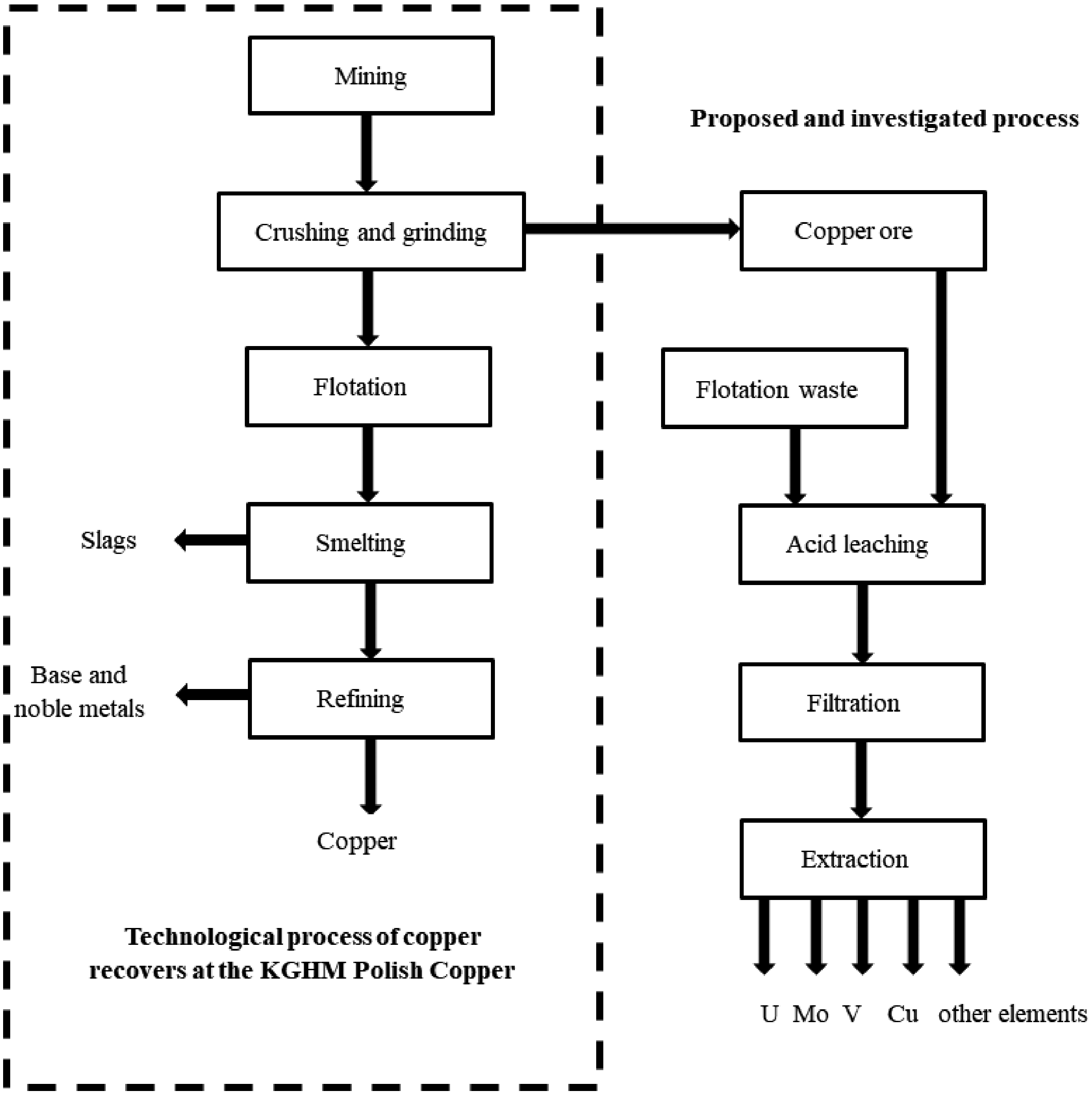


Figure 4: Process for pyrometallurgical refining of Cu ore and hydrometallurgical recovery of metals from flotation tailings or low-grade Cu ore [62].

For both current and future generations of nuclear reactors, such as pressurised heavy water or fast breeder reactors, a nuclear fuel precursor can be produced using the direct approach of UO2 synthesis (with the potential to eliminate the precipitation phase)[38].

Recovery of the Platinum Group Metals

The use of high-grade platinum group metals ore has increased due to their growing industrial demand. Low-grade ore is now more common due to the increasing shortage of high-grade platinum group metals ore. Unluckily, it is prohibitively expensive to extract them from low-grade ore, and doing so raises significant environmental issues. Pt is used as a catalyst in fuel cells to effectively convert O_2 and hydrogen into heat and electrical power. The detection of low Pt levels in biological and environmental samples has been a serious concern with the introduction of Pt-containing catalysts in vehicle exhaust systems. To track the buildup of Pt in the environment, precise and accurate background amounts of Pt in a variety of substances are required. Since Pt is present in sediment samples in such trace amounts, designing techniques to measure it is quite challenging. Developing a process that includes digestion, preconcentration, separation, and Pt detection is an exceptionally effective way to reach incredibly low detection quantities[63]. Utilising a ^{191}Pt radiotracer, the kinetics of the extraction of Pt^{4+} from an HCl solution applying rubeanic acid in TBP, n-butyl alcohol-acetophenone and thenoyltrifluoroacetone (TPA), were studied[63]. Investigating the effects of acidity, mixing duration, Pt quantity, and back-extraction, the most favorable extraction outcomes for TBP and TPA were obtained with 4 and 3 M HCl, respectively. INCT in Warsaw also created a method for recovering Pt from the waste solution. Agua regia was applied as a leaching agent whereas NH_4Cl was used to precipitate Pt for further recovery process, **Figure 6**.

Apart from platinum group metals, precious metals like Au have drawn a lot of interest[10]. Researchers are attempting to use new techniques in both identification and quantitative analysis. A quantity of 0.02 g of Au is

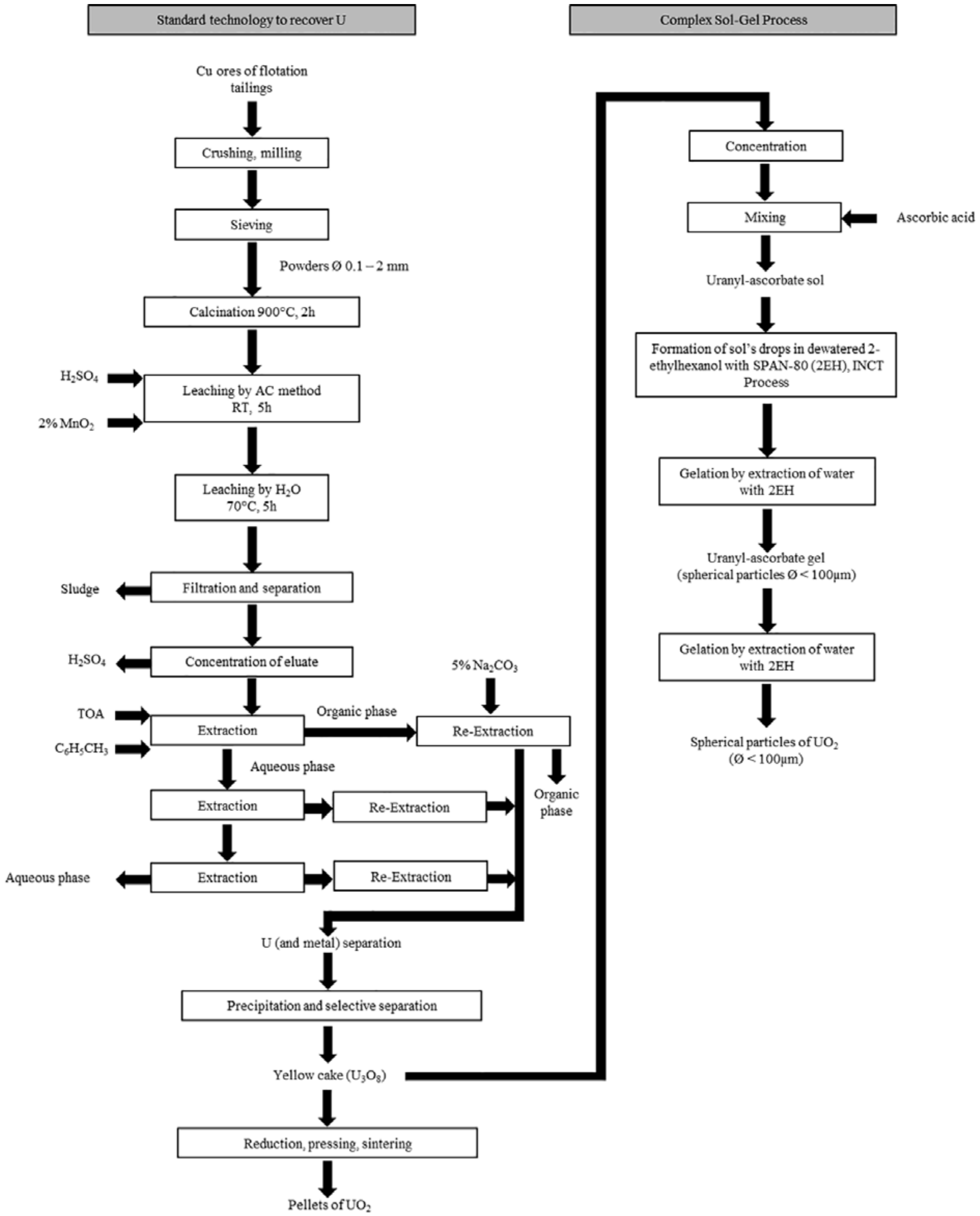


Figure 5: Scheme illustrating the hydrometallurgical procedures for extracting (UO2) from various sources as described in the INCT complex sol–gel approach[38].

often found in a cell phone[10]. The development and use of alternate hydrometallurgical extraction methods has elevated their significance for many research institutions over the past few decades. Societal concern regarding the environmental impacts of cyanidic Au extraction has increased. The Department of Nuclear Methods of Process Engineering, INCT, Warsaw, carried out the development of hydrometallurgical technologies for the separation of metals from waste. The technological line for the solvent extraction of Au from a mixture of Mo-Ni waste was established in **Figure 7**.

Recovery of Rare Earth Elements

Apatite, xenotime, and monazite are a few of the foremost popular minerals that contain REEs. The extraction and reuse of such minerals from various secondary resources has recently attracted a lot of interest. Considering their secondary origin, various techniques have been carried out to separate them from phosphate or phosphogypsum rocks[64]. Extracting them from the aqueous solution (leachate) is a selective activity. For instance, a mixture of minor actinides (MAs) and REEs was used for the extraction studies. La was removed from MA by employing

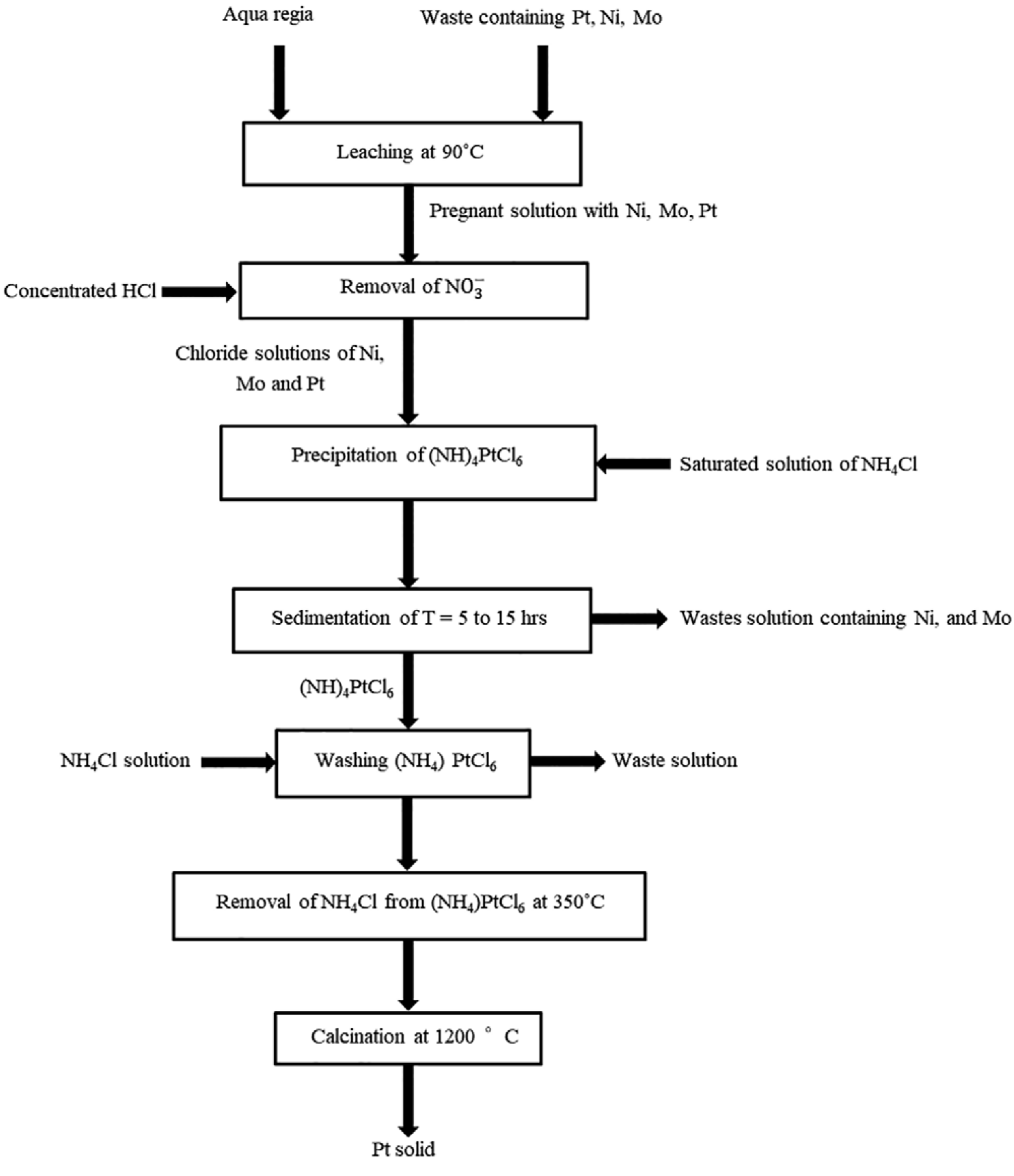


Figure 6: The recovery of Pt from the waste solution.

N,N,N′,N′-tetrakis (4-propenyloxy-2- pyridylmethyl) ethylene-diamine (TPEN) extracting agent. The phase of separation and recovery is intricate and delicate. It is essential to guarantee that each REE separation is highly effective and can be reclaimed at the final stage of the procedure. Knowledge of the extraction characteristics, capacity, phase separation, solubility, selectivity, mass transfer, and economic viability have all been used to develop feasible REE extraction methods[65]. Given their nearly non-volatile nature, low melting point, low flammability, thermal stability, and high ionic conductivity, ionic liquids (ILs) are usually regarded as environmentally friendly solvents and have attracted significant interest. In the extraction of both organic and inorganic materials, ILs made from quaternary ammonium bases and organic acid moieties are frequently utilised[66]. The benefits of ILs, such as high thermal stability and designability, could potentially be introduced through the use of ILs in the solvent extraction of REEs[67]. Numerous factors, such as the kind of acidic medium, diluent, the temperature of the auxiliary agents, metal ions, contact time, organic-to-aqueous phase ratio, pH, and extractant concentration, can have an impact on the process of solvent extraction. Considering various operational conditions that depend on other factors, a particular operational parameter may have various implications on the desired results[68]. It is

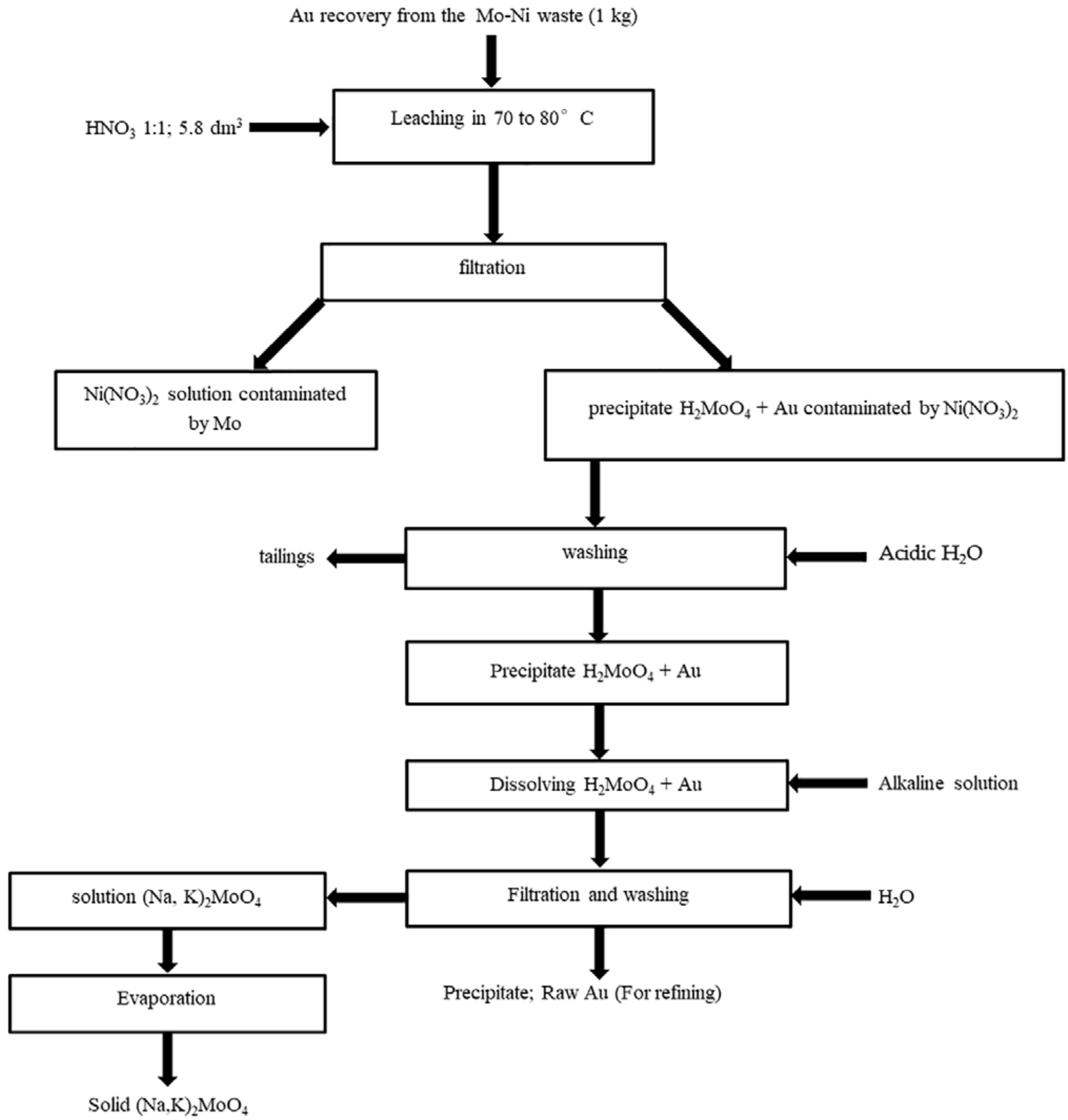


Figure 7: Scheme of Au recovery from molybdenum-nickel waste.

challenging to selectively extract and purify REEs from a pregnant solution[69].

REEs' distribution can also be explored by utilising ILs grounded on phosphinic or phosphoric acids and a metal ion. Due to coordination interactions with moieties of organic and inorganic acids, REEs can produce complex anions (like other metals of side groups). The separation of REEs utilising an IL based on phosphoric acid and an organic base is represented by **Equation 5**[66]:

Equation 5

$$3RNH_3^+A^-_{(org)} + Me^{3+}_{(aq)} + 3Cl^-_{(aq)} \leftrightarrow MeA_3{\cdot}3RNH_3^+Cl^-_{(org)}$$

Aliquat 336 can be treated with KNO_3 to exchange Cl^- with NO_3^- which improves selectivity over REEs, to reduce the viscosity of the extractant and establish a faster mass transfer. **Equation 6** can be used to represent reaction equilibria for A336[NO_3] extraction[70].

Equation 6

$$Me^{3+}_{(aq)} + y(R_3N^+CH_3)NO^-_{3\,IL} + 3NO^-_{3(aq)} \rightleftharpoons (R_3NCH_3)Me(NO_3)_{y+3\ IL}$$

wherein Me^{3+} stands for the elemental cation, $(R_3NCH_3)M(NO_3)IL$ for the *IL* and metal cation complex, and $(R_3N^+CH_3)NO_3^-$ *IL* for A336[NO_3]. *IL* stands for both the IL phase and the aqueous phase. The equilibrium constant Keq is expressed as follows:

Equation 7

$$K_{eq} = \frac{\left[(R_3NCH_3)Me(NO_3)_{y+3\ IL}\right]}{[Me^{3+}_{(aq)}][(R_3N^+CH_3)NO_{3\ IL}^-]^y[NO_{3\ (aq)}^-]^3}$$

Equation 8 may be employed to express the reaction equilibrium for D2EHPA separation.

whereby Me^{3+} stands for the metal cation, [*HA*] for the organic phase's extractant, and [$MeA_3(HA)_3$] for the complex of the extractant and metal. The equilibrium constant K_{eq} is expressed as follows:

Equation 9

$$K_{eq} = \frac{[MeA_3(HA)_3][H^+]^3}{[Me^{3+}][(HA)_2]^3}$$

The separation of REE such as La can be accomplished using the IL [A336][CA-12] in chloride media. Additionally, it was demonstrated that IL[A336][P507] was suited to separate light REEs in chloride media and would work for the isolation of heavy REEs in nitrate media. By applying IL [A336][P507], the Ce^{4+} and F− ions have been effectively extracted from H_2SO_4 solutions and separated[67]. The recovery of mid-heavy REEs in H_2SO_4 solution by [A336][P507] became the subject of a thorough examination. According to the findings, temperature, extractant concentration, and pH all boosted the rate of REE extraction[67]. The results demonstrated that, as both the temperature and extractant concentration increased, so did the distribution ratios of REEs. The influence of pH on the separation behaviors of Tb^{3+} by Cyanex 923, IL [A336][P507], TBP, and P350 (di-(1-methylheptyl)methyl phosphate) is important. Its recovery by Cyanex 923 and TBP in systems of pH = 1.0 to 0.7 improved with rising acidity. At pH < 0, P350 showed a comparable tendency as Cyanex 923 and TBP. Following a reduction in acidity, the Tb^{3+} was extracted more effectively. IL [A336][P507] is more appropriate for the separation of REEs at low acidity, as evidenced by the divergence in recovery performance[67].

Because of the salting-out phenomenon found in the extraction of Lu^{3+}, the recovery of REEs decreased as the concentration of Na_2SO_4 increased. The process of extraction was hindered by the binding of such cations with SO_4^{2-} in the aqueous medium. However, as the concentration of $NaNO_3$ or NaCl increased, the yield of extraction rose as well. The different behaviors of NO_3^-, SO_4^{2-}, and Cl^- complexes could be caused by the ion connection between anions and REE^{3+}, and the hydration effect. A decline in the recovery of metal ions results from the generation of $REESO_4^+$ ions at high sulphate amounts. It is understood that leaching agents for REEs ores of the ion-adsorbed class once included NH_4NO_3, NaCl, NH_4Cl, and $(NH_4)_2SO_4$. NaCl was likewise the first leaching solvent to be widely utilised. As the concentration of NaCl grew, so did the effectiveness of REEs' extraction. The above extraction technique is more effective in extracting mid-heavy REEs than the aqueous medium devoid of NaCl. Al^{3+} and La^{3+} experience low extractability as a result, allowing this technique to be employed to retrieve mid-heavy REEs from the pregnant solution. Following a rise in the concentration of $NaNO_3$, the distribution ratios of all REEs rose, particularly for the mid-heavy REEs. The mixture with $NaNO_3$ has a substantially higher extractability than the one employing NaCl[67].

With heating, the precipitated form of Th and REEs such as Ce created after the recovery process can be dissolved in 4 M HNO^3. Th can be obtained by extracting it with Aliquat 336 diluted in kerosene, stripping it with HCl solution while agitating, and precipitating it as ammonium hydroxide. Ce^{3+} is, on the contrary, oxidised into its tetravalent form by the incorporation of sodium bromate. It can then be recovered by Aliquat 336 in kerosene that contains 1-octanol, stripped by shaking the organic solution with diluted HNO_3 media, and finally precipitated as hydroxide using ammonia. La, Nd, and Y-rich aqueous media can be treated at 25°C by a synergistic TRPO-TOPO combination in kerosene with a 2:1 O/A phase ratio. H_2SO_4 can then be applied to strip the organic media in an equimolar ratio to isolate the majority of the Y, after which, HCl is used as a stripping agent to retrieve Nd and La[71].

In nitrate medium, REEs (Sm and Nd) were extracted from discarded fluorescent lamps using Cyanex 923, which serves as a solvating extractant. Researchers noticed that, although the co-extracted metals took longer than 15 min to reach a state of equilibrium, the REEs did so in just one minute. For greater REE recovery, they recommended low acidity (less than 1 M HNO_3), one minute of reaction time in between the two phases, up to 1 M extractant concentration, stripping with 4 M HNO_3, and scrubbing by HNO_3 or oxalic acid. The REE metal ion was extracted from Nd-Fe-B magnet residue using solvent TBP in IL (Aliquat 336). To improve the distribution coefficient throughout the REE recovery from Ni metal hydride batteries employing chloride medium, [A336]NO_3^- and Cyanex 923 were utilised[52].

To remove REEs and transition metals from Sm/Co and Nd/Fe magnets, Cyphos IL 101 was implemented. Scientists discovered that transition metals are efficiently extracted by the IL, and the maximum distribution rates for Co and Fe, respectively, were attained with 8.5 M and 9 M HCl. The separation coefficients for Sm/Co and Nd/Fe were discovered to be 8×10^5 and 5×10^6, respectively. Transition metals including Co, Mn, Fe, and Zn could additionally be extracted using Cyphos 101 IL from an aqueous media that also contains REEs and Ni with 8 M HCl. Following the initial extraction stage, Cyanex 923 and Aliquat 336 nitrate were employed to recover the REEs from the raffinate. Because Aliquat 336 nitrate is more selective for REEs and can handle less Cyanex 923 molecules around it than Cyphos 101, it is preferred over the latter. A336 chloride and A336 thiocyanate were applied to separate Co and Mn. It was possible to recover La from Ni and Sm from Co through the application of trihexyl (tetradecyl) phosphonium nitrate. REEs were successfully recycled using this technique from used permanent magnets and rechargeable batteries. Here, they added Na or ammonium nitrate to the aqueous media, and the consequence of salting out caused the extraction to improve. They discovered that Sm could be extracted as the pentakis complex $[Sm(NO_3)_5]^{3-}$ and La as the hexakis complex $[La(NO_3)_6]^{3-}$. H_2O was the medium used to do the stripping[52].

Synergistic extraction of REEs can offer the benefit of using reduced usage of the main extracting agent, while still being able to achieve a high rate of separation and replenish the extracting agent. TBP and D2EHPA are two of the most popular and commonly employed of these in the commercial process for the extraction of REEs. Although TBP has a higher loading capacity for REEs compared to D2EHPA, D2EHPA possesses a superior separation coefficient for REEs. An assessment was conducted on the impact of the aqueous phase's concentration of NO_3^- and H^+ ions. Also, an evaluation was conducted on the kind and number of extracting agents present in the organic phase, and on the extraction behavior of La, Nd, Ce, and Y. An organic phase comprising 0.8 M of extracting agents with an equal mole ratio of D2EHPA and TBP in kerosene was employed to test the influence of the NO_3^- ion concentration on the recovery of REEs. The concentration of H^+ ions in the aqueous media was set at 2 M (pH = −0.3). As the amounts of NO_3^- in the aqueous medium increased, the recovery of REE was reported to rise as well. In comparison to the other examined REEs, Y exhibited a higher extraction efficiency. Therefore, when the amount of NO_3^- ions rises, so do the distribution ratios of REEs. A sharp increase in the Y distribution ratio over 6 M NO_3^- was observed. Because the REE^{3+} NO_3^- species were removed following the recovery mechanism of REEs by *TBP*, which is determined according to the reaction in **Equation 10**, a common ion effect could potentially be responsible for the rise in extraction caused by an increase in NO_3^- ions concentration[69].

Equation 10

$$REE^{3+} + 3NO_3^- + \overline{3TBP} \Rightarrow \overline{REE(NO_3)_3(TBP)_3}$$

With an increase in the concentration of H+ in the aqueous media, the distribution coefficient of REEs dropped. Relative to other REEs, Y is particularly susceptible to changes in the concentration of H^+. The cation exchanger extracting agent D2EHPA's recovery mechanism is capable of being used to illustrate how H^+ affects REEs extraction. Below is the equation showing the extraction mechanism of REEs from aqueous media using D2EHPA:

Equation 11

$$REE^{3+} + 3\overline{H_2A_2} \Rightarrow \overline{REE(HA_2)_3} + 3H^+$$

Precipitation

The extracted metals can be recovered in solid form by precipitation. This is realised through the combination of selected ion(s) with an appropriate counter ion in adequate concentrations to surpass the subsequent compound's solubility product and produce a supersaturated solution. Precipitation occurs at lower temperatures, low ion concentration, a high degree of supersaturated solutions, and a minimal stirring of the solutions. The size of the precipitate depends on the type of solvent and pH of the solutions. Metals from sources such as acid mine drainage are normally precipitated as metal oxides, phosphates, sulfides, hydroxides, and carbonates[72].

The precipitation technique is easy to control, simple, inexpensive, and applied in industry. Double-salt precipitation, simple precipitation, and oxidative precipitation are the techniques utilised in hydrometallurgy for secondary resources and primary ores. In simple precipitation, precipitants such as OH^-, $C_2O_4^{2-}$, S^{2-}, and CO_3^{2-} are applied[73]. Generally, double-salt precipitation entails the use of salt with more than one anion or cation. Double-salt precipitation is crucial in the recovery of REEs. When some compounds are precipitated or eliminated from a solution by oxidation, the term "oxidative precipitation" is generally used. In other cases, some metal ions can be precipitated by adding complexing agents to form complexes when ligand ions or ligand molecules are available[73]. In most cases, a complexing and precipitating agent can be used together for improved and selective recovery of a metal such as Ni, Mn, Co, Cu, and Fe. For such metals, OH^-, CO_3^{2-}, and S^{2-} precipitants combined with NH3 as a complexing agent are effective in complexation–precipitation.

Ion Exchange

Ion exchange is among the separation techniques that play a big role in the recovery of a wide range of metals with unique properties suitable for the current and future economy. Due to intense mining activities, metals have significantly reduced in ores, and they exist in low concentrations. The ion exchange technique is suitable for the recovery of such metals. That is attributed to its environmental safety, selectivity, powerful resolving ability, high efficiency, moderate cost, and suitability for combination with subsequent techniques in the recovery of noble metals and other applications[74,75]. Ion exchangers with distinct functional groups, due to their good kinetic properties, high mechanical strength, and exchange capacity, increase their suitability in the concentration of microscopic amounts of metals, extracting them in the presence of accompanying components.

Ion exchange resins acting like porous media are essential in separation industries because of the elimination of thermal regeneration, a higher metal ion loading capacity, higher loading rate, and being less prone to fouling by organic materials. The porous property of the resin leads to enhanced adsorption rates because of the improved diffusion of the ions. The metal recovery process's efficiency is firmly reliant on the contact time, pH of the solution, ion concentration, and ion coordination/exchange resin properties such as structure and type of the ligand, crosslinking degree, and swelling[76]. Various types of exchange resins are available commercially in the recovery of metals; for example, Amberlite IR-120 can be used in separating Cu^{2+}, Zn^{2+}, and Cd^{2+}. Chelating ion exchange resins such as Amberlite IRC 748 and Chelex 100 have aminodiacetic acid functional groups to exchange Zn^{2+} and Cu^{2+} from aqueous solutions while macro-porous AMBER JET 1200 Na cation exchange resins are efficient in the separation of metals such as Ni^{2+} and Pb^{2+}[77]. In the recovery of platinum group metals such as Pa^{2+}, Pt^{2+}, and Pt4+ from HCl acid solutions, CYBBER and Purolite grades present high sorption capacity for the anion exchange[74].

RECOVERY OF STRATEGIC AND CRITICAL METALS USING FLOTATION

Flotation is essentially a surface selectivity-based extraction method that separates the hydrophilic portion of a material from the hydrophobic portion. To create a wide range of separations, this technique selectively modifies the hydrophobicity of the mineral surfaces using several surfactant chemicals[27]. While gangue minerals – unwanted minerals – remain in the water, the target minerals, which are frequently sulphide minerals, are usually hydrophobic and will adhere to the air bubbles[78-82]. The subsequent froth rich in minerals is subsequently scraped off the flotation cell's surface, **Figure 8**.

If flotation techniques used in other regions are tailored to suit the current minerals, they will be essential for the beneficiation of the minerals in Kenya. Research was conducted to recover Cu and Co by treating the tailings from the flotation of Cu and Co oxidised ores produced at the Kambove Concentrator (DRC). The study focused on determining the dosage of chemicals needed to float the examined tailings and recover the maximum amounts of Cu (44.80%) and Co (88.30%). Centered on the concentrate grade (3.31% Cu and 2.22% Co) and the feasible extraction of the metals of interest, it was determined that flotation was a desirable method for reprocessing the tailings[83]. The tailings from the processing of Cu ores contain rocks that may be recycled as inexpensive raw materials. The overconsumption of reagents due to the particle size distribution in a wide range of slimes is still an obstacle. Such an issue should be taken into consideration for the most effective technical and financial implementation of the aforementioned technique. While the wastewater produced by the flotation of tailings can be reclaimed and fed back into the Kambove Concentrator milling process, the tailings can be added to construction materials as cemented pastes[83].

Slags are also known to have valuable metals, and instead of being an end waste, they can serve as a secondary source of metals[84,85]. They come in a variety of forms, as wastes from combustion processes or as the results of metallurgical operations. They have been used in numerous fields as a resource material[85]. Furthermore, for certain purposes, the characteristics of slags are as good or better than those of competing materials. From nonferrous smelters, a range of nonferrous slags are generated.

Numerous investigations on metal recovery using nonferrous slags have already been conducted. A large number of studies focused on recovering metals from Cu slags[85,86]. By considering variables, including the form of the processed ore, the kind of furnaces employed, and the cooling techniques, the chemical composition of Cu slags from various sources might range significantly. The main phases in crystalline Cu slag are often fayalite and various silicates. Most of the time, Ni and Co are found as oxides where the Co distribution in the slags is extremely homogeneous. On the other hand, many Cu slags have diverse types of Cu minerals. They could take the shape of oxides, sulphides, or a combination of the two. Investigations were conducted on the recovery of Cu and Co from ancient Cu slags collected from the Küre Plant basin of Turkey[86]. The slag was of the fayalitic kind, which contained 1.24% Cu, 53.16% Fe, and 0.53% Co. To retrieve the metal values, two distinct paths were taken. The first method was leaching it after after roasting it with pyrite (FeS_2). The second method involved leaching, and roasting the flotation tailings with FeS_2, followed by flotation of the slags. It was discovered that the second method worked well for treating the Cu slag. During the flotation process, a Cu concentrate with around 11% Cu was created, and 77% of the Cu was recovered, leaving 93% of the Co in the tailings[86].

Due to the small amounts of platinum group metals in primary ores (less than 10 g/ton) and the complex processes involved, their extraction from primary ores is costly. Ores (such as Merensky Reef ore grades, which comprise 3 to 8 g/t platinum group metals tied to Ni, Cu,

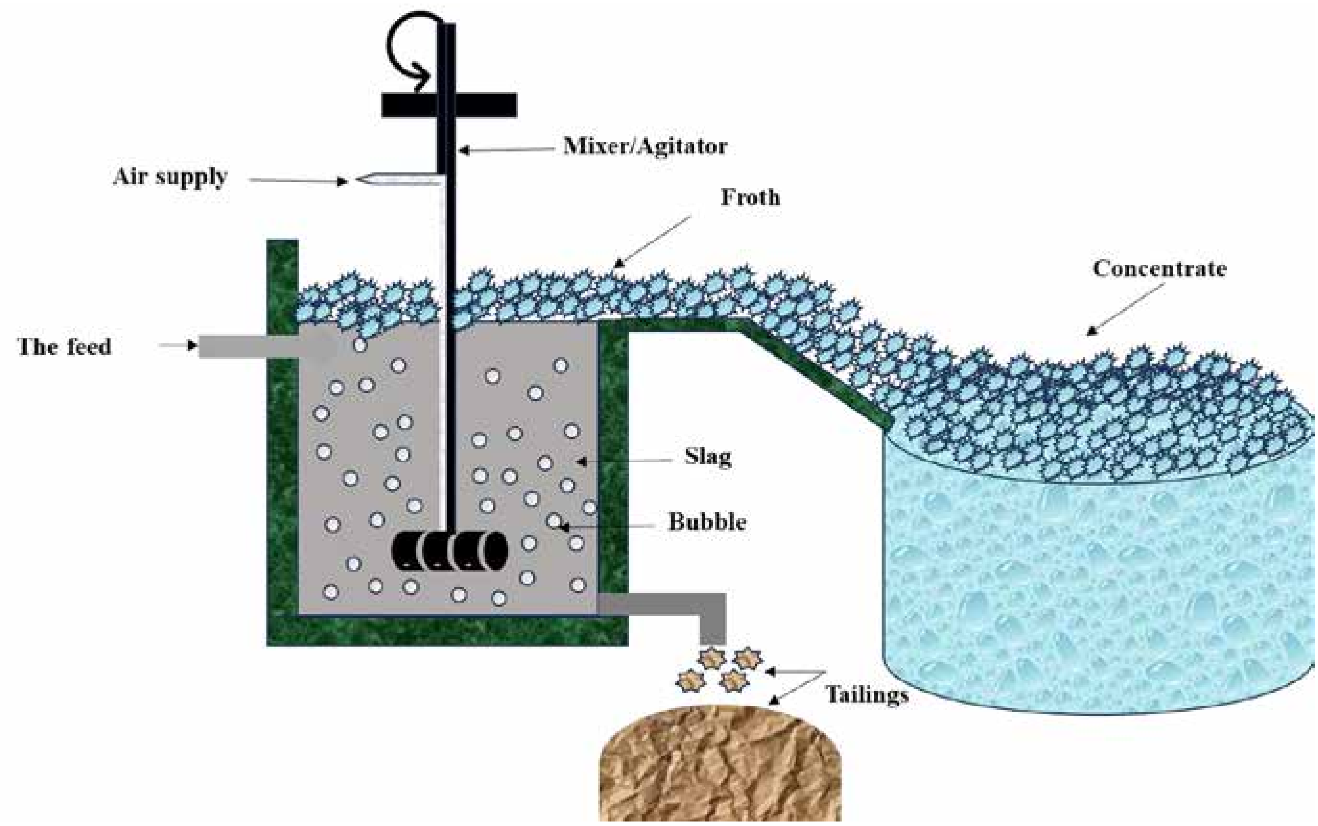


Figure 8: A sketch of the froth flotation process.

as sulphides) are mined, ground, processed through gravity separation, and floated. Their concentrate, which is generally 200 to over 2000 g/t platinum group metals alongside 0.4% to 2.8% Cr_2O_3, undergoes meltdown at excessive temperatures (>1500°C). Thereafter, they are purified through hydrometallurgical processes[87]. Traditionally, froth flotation has been used to extract platinum group metals from pure (unweathered) sulphide ores. This method usually yields recoveries of over 85% for Pt. The efficient concentration of such metals through flotation in virgin sulphide ores is dependent upon the presence of highly floating base metal sulphide minerals, such as pyrrhotite, chalcopyrite, and pentlandite. Nevertheless, as an alternate source for keeping up their production, the rapid depletion of sulphide platinum group metal-bearing minerals has sparked a lot of interest from scientists. The focus has been on investigation of their recovery from near-surface oxidised metal ores.

Besides platinum group metals, Au can be extracted using the flotation technique[25,43]. Au floats easily, and it is possible to separate free Au from sulfide-containing ore via selective flotation. A product that is directly smeltable could potentially be produced by removing the floating Au from the sulphides. According to research, selective flotation of Cu sulphides could be observed from FeS2 ores at pH values higher than 11[88]. The behavior of the free Au in these circumstances was less obvious. Additional collectors (monothiophosphates) could be included for increased Au recovery because they are known to be selective Au accumulators[88,89]. Researchers looked into how several operating factors, such as pH, collector additions, and grind size, affected the efficacy of Au flotation[88]. With a variety of collectors, Au was recovered selectively against FeS2 at elevated pH levels. Nevertheless, in the flotation tests, there was no specificity towards chalcopyrite. Granular Au drifted towards the flotation tail, but fine Au floated more readily. That is because the flotation of Au is highly dependent on some parameters like the type of the collectors, size, structures, and the mineral containing Au, amongst others.

Numerous studies have also been conducted to examine the dynamics of flotation of REEs in terms of pulp chemistry, froth stability, mineral particle size distribution, and collector–mineral surface interactions[90]. The flotation effectiveness of REEs is measured by the flotation rate test, which considers concentrate grade, mass pull, and recovery. The flotation kinetics of the mine is defined as the fluctuation in the recovery of metals over time. The outcomes are utilised to characterise a mineral's flotation behavior in specific flotation conditions. The flotation rate of the REEs depends on the length of flotation, pulp pH, the kind and dose of the collector, the extent of surface–collector contact, and the mineral species. The principal materials that are the primary industrial sources of REE minerals are monazite $(REE)PO_4$ (55 to 60% RE oxides), xenotime $(REE)PO_4$ (55 to 60% RE oxides), and bastnaesite $[REE(CO_3)]F$ (70 to 75% RE oxides). Flotation is considered to be one of the most essential methods for separating REEs from related minerals and producing concentrates. The resulting material often contains 60 to 70% mixed REEs, due to the intricate and fine properties of the REE ore[91].

The assessment was done on the flotation of rare earth oxide (REO) in monazite by combining hematite (Fe_2O_3) and quartz (SiO_2) with hydroxamic acid[90]. The results of the micro-flotation experiments carried out on individual minerals demonstrated that each model mineral's flotation response depends on pH. The optimal flotation extraction of quartz happened at pH = 3, while that of hematite and monazite was attained at pH = 7. As predicted, adding more hydroxamic acid increased each mineral's flotation yield. When the dose of hydroxamic acid was increased, the specificity coefficients of monazite over quartz remained lower than those of monazite against hematite. In a mixed minerals flotation, it was anticipated that a higher percentage of Fe_2O_3 would be associated with REO in flotation concentrates than SiO_2. The outcome suggested that depressants are necessary to accomplish selective beneficiation and extraction of REO. Further results on heterogeneous minerals separation experiments demonstrated that, in the absence of depressants, the flotation of REO from SiO_2 and Fe_2O_3 was unselective. It was reported that 96% Fe_2O_3, 99% REO, and 80% SiO_2 recoveries of the concentrate were produced by a 2000 g/t hydroxamic acid collector. Whenever 4000 g/t starch was employed, the extraction effectiveness of REO rose from its low average of 6.42% devoid of depressants to 44.78%. Matching recoveries of 93% REO, 38% SiO_2, and 81% Fe_2O_3 were observed. Contrarily, when Na_2SiO_3 was utilised, the resulting concentrates had greater gangue contents (SiO_2 > 60% and Fe_2O_3 > 90%). That resulted in lower REO separation efficiency. When hydroxamic acid was present, starch provided a better REO upgrade. Nevertheless, Na_2SiO_3 was a better choice when REO recovery was the only factor considered. Furthermore, a mixture of starch and Na_2SiO_3 demonstrated considerable recoveries[90].

The beneficiation reaction of gangue minerals and REE in the tailings differs noticeably. The separation techniques of froth flotation, wet magnetics, and gravity led to widely differing REE upgrades and recoveries. A flotation study was conducted on the ore by applying sodium oleate acting as a collector. To determine if there was a possibility of extracting and enriching REE minerals in saprolite ore, a study examined three distinct treatment configurations: the relative impacts of pulp pH, depressants, and de-sliming. Most REE minerals (>50%) could be extracted using flotation methods on raw feed. However, the technique was not selective, given that clay minerals and silicate gangue also found their way into the flotation concentrate together with the REE minerals. The specificity of the flotation of REE minerals was enhanced by de-sliming before flotation, using a mixture of depressants (Na_2SiO_3 and starch). That resulted in concentrates that had total REO grades of 5.87% and 4.22%. Recovery yields of 45% and 50% at pulp pH = 9 and 10.5 were obtained. Because of their fine-to-ultrafine properties, clay gauge and silicate minerals were collected through the synergistic process of surface activation and entrainment. A random grade–recovery relationship was found when all test results were compared. It indicated that there could be a need for more flotation tests where its process limitations can be looked into. Optimisation is also necessary to further maximise both REE recovery and grade. Additionally, the possibility of employing magnetic separation was raised[92]. Apart from the physical methods, ILs have been seen as revolutionary in the flotation of REEs. Tetraethylammonium mono-(2-ethylhexyl)2-ethylhexyl phosphonate ([N2222][EHEHP]) is an IL that has been studied earlier for REE solvent extraction and revealed to be selective and efficient. For the first time, [N2222][EHEHP] was assessed as a collector in bastnäsite flotation, which is the main deposit for producing REEs[93]. The findings were contrasted with two typical gangue minerals found in quartz and hematite. Hematite exhibited an enhanced collectability of [N2222][EHEHP] over bastnäsite, which significantly recovers at pH = 5 with an increased dosage of IL (500 g/t). It implies that these minerals' extraction mechanisms could not be the same. Based on the Fourier transform infrared spectroscopy (FT-IR) data, [EHEHP] moiety adsorption on bastnäsite was verified. It seemed to be most effective in slightly acidic pH conditions. The micro-flotation data, which indicated that bastnäsite recovery was maximum (~50%) at pH = 5, was consistent with this. Furthermore, micro-flotation indicated that a very high dose of IL must be administered to directly float bastnäsite. Protons may interact with $[EHEHP]^-$ and obstruct interactions between REE ions and $[EHEHP]^-$, which explains why bastnäsite flotation recovery is lower at pH = 3. According to FT-IR data, the adsorption of the $[EHEHP]^-$ moiety on hematite is evident in acidic conditions, which matches the micro-flotation recovery pattern. Furthermore, hematite may be more recoverable because of its better yield compared to bastnäsite. The little recovery for quartz at both dosages across the pH range under test signified the absence of reagent adsorption. By using magnetic separation to examine the concentrates and tails, it was discovered that higher collector dosages might result in bastnäsite recovery capacities over 90% and an optimal conversion ratio of 1.7[93].

PROPOSALS AND PROSPECTS FOR FUTURE APPLICATION OF THE HYDROMETALLURGICAL AND FLOTATION TECHNIQUES

In 2016, Kenya implemented the Mining Act meant to modernise and expand the mining industry. Even though the Act was improved from the previous legislation, output in the mining sector remains poor. However, the new regime announced the removal of the moratorium in 2023. The Government emphasised the importance of creating a good business atmosphere for stakeholders and investors. Kenya's future development of the mining sector will be influenced by environmental impact and the adoption of sustainable mining techniques. Given the rising number of international mining firms promising to decarbonise and achieve net zero goals, the mining sector should develop practical approaches to tackle environmental issues in their operations. The approach will compel investors to apply environmentally justifiable techniques for metal recovery.

As Kenya seeks to diversify its mining practices, hydrometallurgical and flotation procedures emerge as a compelling alternative. These innovative approaches will not only address the constraints posed by low-grade ores but also align with global sustainability goals. Through investment in research and regulatory and infrastructure adaptations, Kenya can pave the way for a dynamic and responsible mining sector. That will contribute to both economic development and environmental preservation.

The metal recovery techniques outlined in this article can easily be applied to the needs of the Kenyan mining industry. The development of advanced leaching technologies can enhance the efficiency and selectivity of metal extraction. Continuous research and investment in these technologies can optimise the recovery of strategic and critical metals. One of the challenges in Kenya's mining industry is the presence of low-grade ore deposits. Hydrometallurgy offers a viable solution, enabling the cost-effective extraction of metals from ores that were previously considered economically unviable. Such an option becomes crucial in times of depleted mineral reserves for important metals, when alternative sources must be explored. Beyond primary ores, hydrometallurgy provides an avenue for recovering metals from secondary sources. With the growing demand for recycling and a circular economy, Kenya can leverage hydrometallurgical procedures to extract valuable metals from secondary sources, contributing to resource sustainability. The mining research institutions in Kenya will need to also initiate progressive efforts to enhance the efficacy of the flotation process. That could encompass the implementation of advanced control systems or the formulation of improved surfactants.

There will be a need for the establishment and demonstration of pilot plants to exhibit the effectiveness and feasibility of the described methods. That can be reinforced by introducing capacity-building programs and training dynamism, to equip local experts with the knowledge required to operate flotation and hydrometallurgical processes. Collaboration with research institutions, both domestically and internationally, can fast-track the development of competent and environmentally friendly metal-recovery processes tailored to the country's mineral resources. In addition, regulatory frameworks ought to be adapted to address the drawbacks and opportunities associated with chemical-based techniques for metal recovery. Clear guidelines, environmental impact assessments, and monitoring mechanisms should be established to foster responsible mining practices.

CONCLUSIONS

The vast unexploited mineral resources in Kenya present a major opportunity for economic development. Nonetheless, the environmental impacts of mining in the region cannot be neglected. Mineral extraction processes require a well-adjusted approach that considers both sustainability and economic returns. The adoption of modern flotation and hydrometallurgical methods emerges as an important solution to efficiently extract strategic and critical metals while reducing environmental effects. For full balance in society of a sustainable and new world, we must not forget about people. Skillful management of natural resources and investment in local communities should guarantee stable and peaceful development. The mining industry and government stakeholders must adopt sustainable technologies, while prioritising responsible mining practices. All-inclusive and collaborative steps are necessary for harnessing Kenya's potential mineral wealth, while protecting the delicate balance of its environment.

Please note that references and reading can be obtained using the following link: https://www.mdpi.com/2075-163X/14/1/21#:~:text=of%20the%20country.-,Because%20Kenya%20was%20originally%20mapped%20as%20an%20agricultural%20region%2C%20less,is%20largely%20neglected%20for%20minerals.

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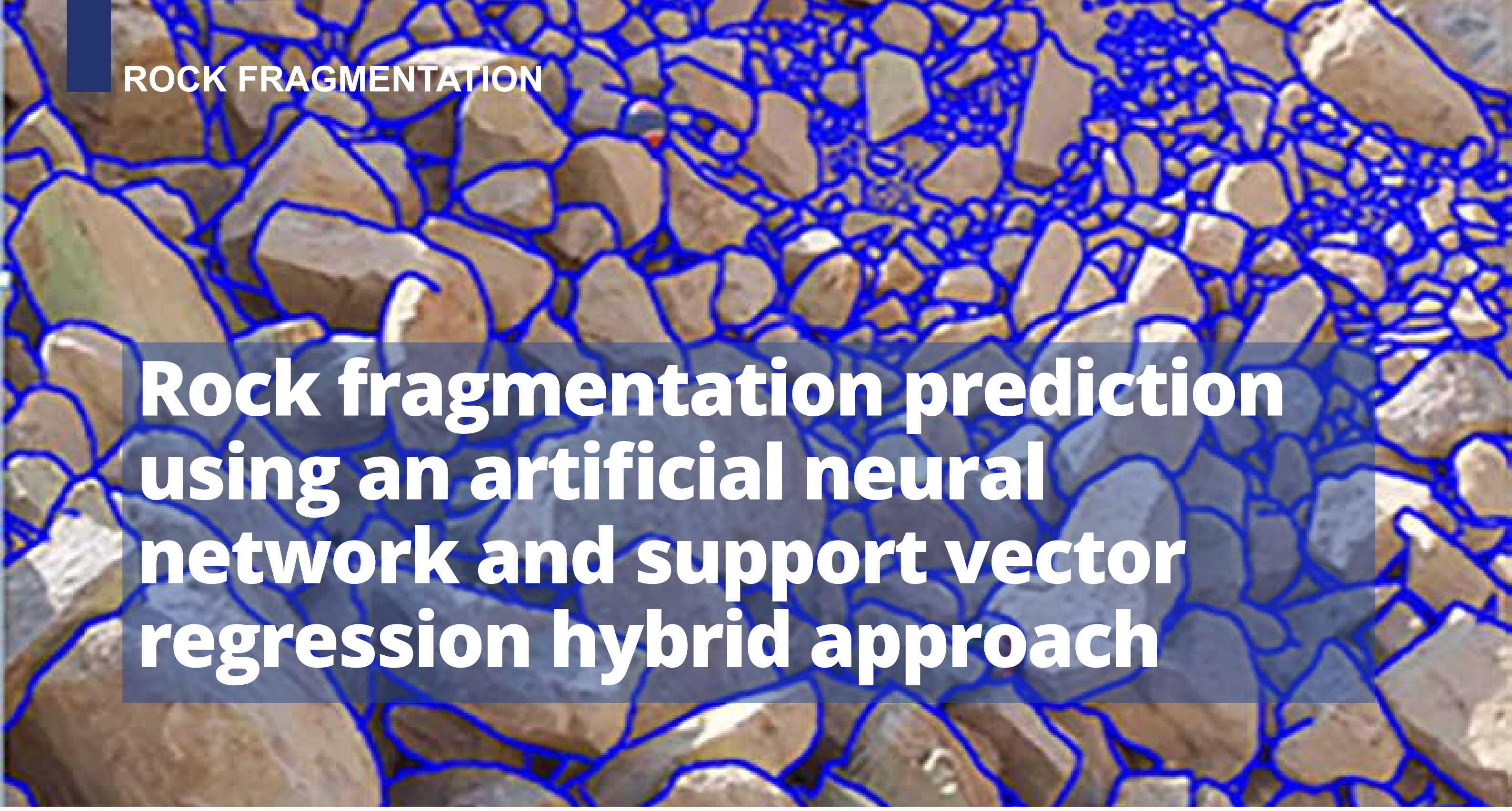

Rock fragmentation prediction using an artificial neural network and support vector regression hybrid approach

While empirical rock fragmentation models are easy to parameterize for blast design, they are usually prone to errors, resulting in less accurate fragment size prediction. Among other shortfalls, these models may be unable to accurately account for the nonlinear relationship that exists between fragmentation input and output parameters. Machine learning (ML) algorithms are potentially able to better account for the nonlinear relationship. To this end, we assess the potential of the multilayered artificial neural network (ANN) and support vector regression (SVR) ML techniques in rock fragmentation prediction. Using geometric, explosives, and rock parameters, we build ANN and SVR models to predict mean rock fragment size. Both models yield satisfactory results and show higher performance when compared with the conventional Kuznetsov model. We further demonstrate an automated means of analyzing a varied number of hidden layers for an ANN using Bayesian optimization in the Keras Python library.

INTRODUCTION

Rock fragmentation is the process by which rock is broken down into smaller size distributions by mechanical tools or by blasting. The resulting fragment size distribution may be characterized by a histogram showing the percentage of sizes of particles, or as a cumulative size distribution curve[1]. The primary means of rock fragmentation in mining is blasting. A good blast produces a size distribution that is well suited to the mining system it feeds, maximizes saleable fractions, and enhances the value of saleable material[2]. Blasting efficiently saves significant amounts of money that would otherwise be spent on secondary blasting[3]. It also yields significant savings on the costs of downstream comminution processes, i.e., crushing and grinding.

The results of a blast depend on several parameters, which are broadly categorized as controllable and uncontrollable[4,5]. Controllable parameters can be varied by the blasting engineer to adjust the outcome of blasting operations. Controllable parameters can be grouped into geometric, explosives, and time parameters. Geometric parameters include drill hole diameter, hole depth, charge length, spacing, burden, and stemming height. Explosives parameters include the type of explosive, explosive strength and energy, powder factor, and priming systems. Time parameters include delay timing and initiation sequence. A blasting engineer's ability to change these controllable parameters dynamically in response to as-drilled information is critical to achieving good fragmentation[3]. The uncontrollable parameters constitute the geological and geotechnical properties of the rock mass. These parameters are inherent, and thus, cannot be varied to adjust blasting outcomes. They include rock strength, rock-specific gravity, joint spacing and condition, presence and depth of water, and compressional stress wave velocity[6]. Though these parameters cannot be varied by the blasting engineer, adequately accounting for them in a blast design helps to achieve good fragmentation. **Figure 1** is a bench blast profile showing a variety of design parameters.

Several studies have sought to predict fragment size distribution based on the parameters used in blast design. The accurate prediction will give blasting engineers control over the outcome of blasting operations. Consequently, engineers will know which controllable parameters to modify, and to what extent the modification should be. Having an accurate prediction model leads to good post-blast results, and this comes with enhanced loader and excavator productivity along with numerous downstream benefits. However, the

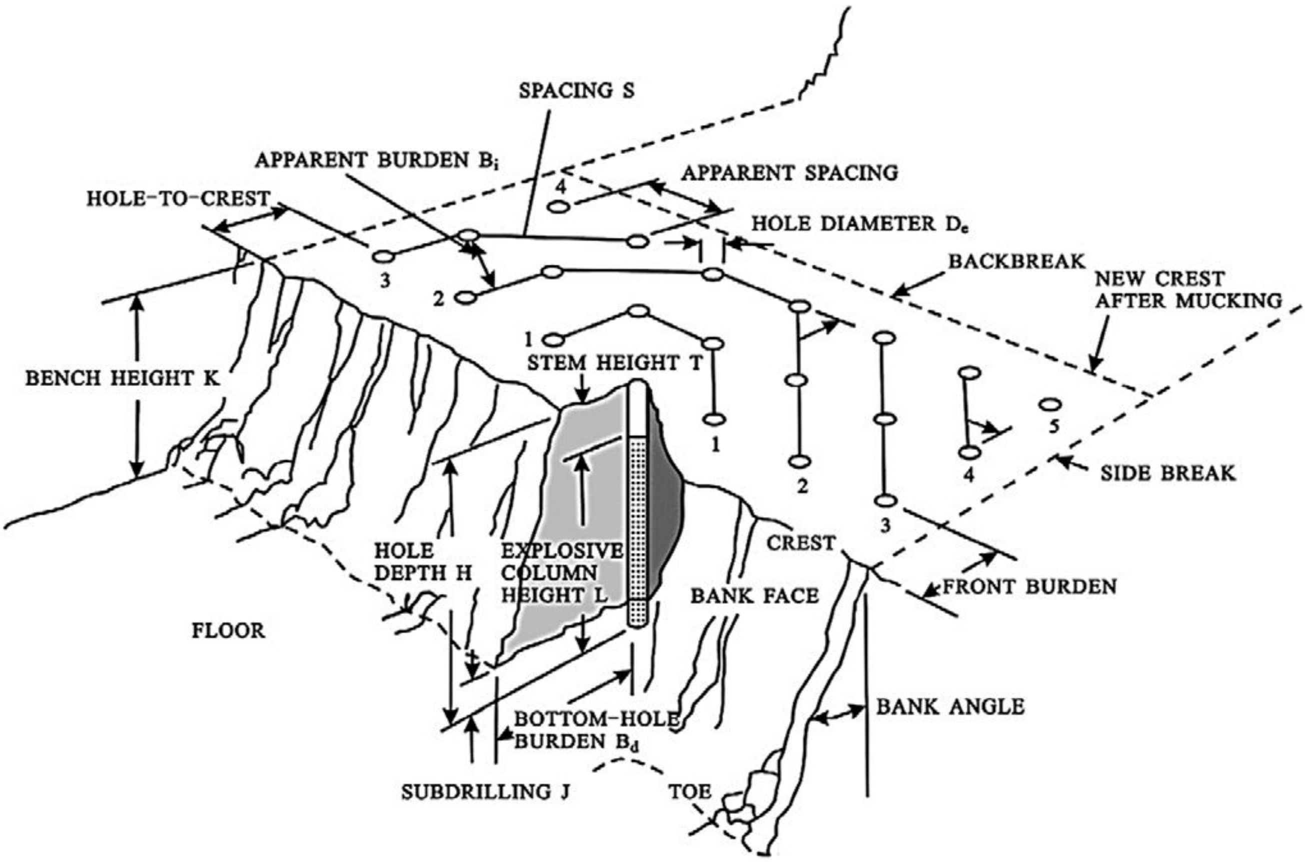

Figure 1: Blast design terminology[5].

prediction exercise proves to be challenging considering that numerous parameters influence fragmentation. Additionally, the rock mass may be heterogeneous and/or anisotropic in its structures of weakness. To this end, it is impossible to develop a predictive tool solely based on theoretical and mechanistic reasoning[5]. Researchers have thus mostly resorted to empirical techniques in predicting the outcome of fragmentation, with the Kuz-Ram being the most widely used. The empirical models are favored and widely used in daily blasting operations because they are easily parameterised. A major shortfall, however, with the empirical methods is that certain significant parameters are not accounted for, and this leads to less accurate results. Cunningham[2], notes that essential parameters omitted by empirical techniques include rock properties and structure, eg, joint spacing and condition, detonation behavior, and mode of decking. Other parameters include blast dimensions and edge effects from the borders of the blast. Over the years, researchers have modified existing models and formulated new ones in an attempt to improve prediction accuracy. While this has contributed to significant improvement, none of the ensuing models incorporate all the important parameters, and accuracy is still of concern. In some instances, highly simplified or inappropriate procedures were used for estimating the properties of structural weakness in the rock mass[5]. Furthermore, the relationship between fragmentation input and output parameters is highly nonlinear, and empirical models may not be well suited for such modeling.

To this end, researchers, in recent years, have sought to implement machine learning (ML) techniques for fragmentation prediction. The objective was to capture as much of the inherent nonlinearity using limited input parameters and subsequently improve accuracy. Kulatilake *et al.5* and Shi *et al.*[7] have respectively exploited the potential of using artificial neural network (ANN) and support vector regression (SVR) for this purpose, and have achieved satisfactory results. ANN and SVR are machine learning techniques that are proven to possess high nonlinearity-recognition properties. However, ANN models in the rock fragmentation literature were limited to only one hidden layer, and do not exploit the potential of the multilayered network (ANN with more than one hidden layer), which could potentially lead to achieving higher accuracy. In this research, we implement SVR and a variety of multilayered ANN for predicting mean fragment size.

Machine learning (ML) is a branch of artificial intelligence (AI) that allows computer systems to improve their performance at a task through experience (learning) for the purpose of predicting future outcomes[7,8]. It is a multidisciplinary field that relies significantly on specialized subject areas such as probability and statistics, and control theory. ML techniques are broadly classified as supervised and unsupervised learning. Supervised learning is concerned with predicting an outcome given a set of input data. It does so by making use of the already established relationship between representative sets of input and output data that were used for model training. Unsupervised learning is concerned with data segmentation based on pattern recognition. Unsupervised ML techniques can infer patterns from data without reference to known outcomes. They are useful for discovering the underlying structure of a given data set. The rock fragmentation problem is a regression problem that is suited to tools of supervised machine learning such as multivariate regression analysis, artificial neural network (ANN), and support vector regression (SVR). The last two comprise algorithms that are more robust to nonlinear relationships between input and output data[5,9]. They are thus considered in this study since rock fragmentation input and output parameters are nonlinearly related.

PRELIMINARY BACKGROUND

We provide a fundamental explanation of the machine learning techniques used in this study. The section describes the architecture of the artificial neural network and support vector regression.

Artificial Neural Network (ANN)

Artificial neural network (ANN) is a machine learning technique that is inspired by the way the biological neural system works, such as how the brain processes information[7,8,10]. Information processing in ANN involves many highly interconnected processing elements known as neurons that work together to solve specific problems. The learning process involves adjustments to the synaptic connections existing between the neurons[7,11]. In the biological neural system, a neuron consists of a cell body, known as soma, an axon, and dendrites. The axon sends signals, and the dendrites receive these signals. A synapse connects an axon to a dendrite. Depending on the signal it receives, a synapse might increase or decrease electrical potential. An ANN consists of a number of neurons similar to human biological neurons. These neurons are known as units and are connected by weighted links that transmit signals from one neuron to the other[7,12]. The output signal is transmitted through the neuron's outgoing connection, which is analogous to the axon in the biological neuron. The outgoing connection splits into a number of branches that transmit the same signal. The outgoing branches terminate at the incoming connections (analogous to dendrites) of other neurons in the network[7].

An ANN has three types of neurons, and these are known as input, hidden, and output neurons. They are stacked in layers, and receive input from preceding neurons or external sources, and use this to compute an output signal using an activation function. The activation function is a mathematical formula for determining the output of a neuron based on the neuron's weighted inputs. The output signal is then propagated to succeeding neurons. While this is ongoing, the ANN adjusts its weights in order to record an acceptable minimal error between input variables and the final output variable(s)[13]. The complexity of the ANN architecture makes it well suited for solving both linear and nonlinear problems[10]. Advancement in computational power has enhanced its use in the fields of engineering, industrial process control, medicine, risk management, marketing, finance, communication, and transportation.

Suport Vector Regression (SVR)

Support vector regression (SVR) is a type of supervised machine learning that is based on statistical learning theory[14]. Just like the ANN, SVR is efficient at modeling nonlinearly related variables and does well at solving both classification and regression problems. It works by nonlinearly mapping, i.e., transforming, a given data set into a higher dimensional feature space, and then solving a linear regression problem in this feature space[9,15]. That is, it seeks to predict a single output variable ($\hat{y}$)as a function of *n* input variables (x) using a function $f(x)$ that has at most ε deviation from the actual values (y) for all the training data[16]. **Equation 1** expresses this function in its simplest form as a linear relationship[9]:

Equation 1

$$f(x) = b + w \cdot \varphi(x)$$

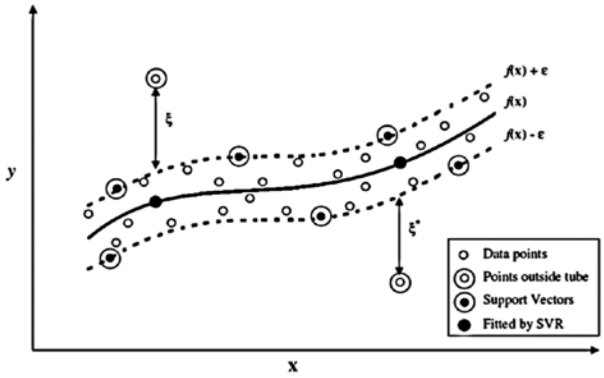

Figure 2: Graphical representation of support vector regression[17].

In **Equation 1**, the function $\varphi(x)$ denotes the high dimensional kernel-induced feature space. Kernel refers to the mathematical function used in the data transformation process. Different kernels are available for use in SVR analysis. They include the linear, polynomial, radial basis function (rbf), and sigmoid kernels. Parameter w in **Equation 1** is a weight vector, and b is a bias term. Both w and b are calculated by minimizing a regularized cost function. **Figure 2** is a graphical representation of the SVR concept. The $\pm\varepsilon$ deviation from the actual values (y) can be described as a tube that contains the sample data with a certain limit ε[16]. This implies that the function $f(x)$ is constrained by the $\pm\varepsilon$ limits to form a tube that represents the data set with the expected deviations.

LITERATURE REVIEW

The ability to accurately predict fragment size distribution from a given blast design will give blasting engineers control over the outcome of blasting operations. Engineers will be able to identify which controllable parameters to modify, and to what extent the modification should be. To this end, several studies have sought to predict fragment size distribution based on the parameters used in blast design. These studies have resulted in empirical prediction models, with the Kuz-Ram being the commonest model in use. Others include the CZM, two-component model (TCM), Kuznetsov-Cunningham-Ouchterlony (KCO), SveDeFo, and Larson's equation[4,18]. The reliance on empirical models stems from the complexity that comes with the attempt to develop explicit theoretical and mechanistic equations to predict the outcome of fragmentation[2,4,5]. This complexity is primarily attributed to the fact that there are so many parameters that affect a blast, coupled with geological heterogeneity[5,9].

The Kuz-Ram model is essentially a three-part model consisting of a modified version of the Kuznetsov equation, the Rossin-Rammler equation, and the Cunningham uniformity index. The parameters defined by these equations constitute the output of the prediction model[4]. The Kuznetsov equation is for predicting mean fragment size (X_{50}), and the original version is given by Kuznetsov[19] as:

Equation 2

$$X_{50} = A\left(\frac{V}{Q}\right)^{0.8} Q^{0.167}$$

In **Equation 2**, X_{50} is the mean fragment size (cm); A is the rock factor (7 for medium hard rocks, 10 for hard but highly fissured rocks, 13 for very hard, weakly fissured rocks); *V* is the rock volume (m^3); and *Q* is the weight of TNT (kg) equivalent in energy to the explosive charge in one borehole. A shortfall of the equation is that the rock mass categories it defines are very wide, and thus need more precision[5]. Cunningham[20,21] provides a modified version of the equation as follows:

Equation 3

$$X_{50} = AK^{-0.8}Q^{\frac{1}{6}}\left(\frac{115}{RWS}\right)^{\frac{19}{20}}$$

In **Equation 3**, *A* is the rock factor, and varies between 0.8 and 22 depending on hardness and structure; *K* is the powder factor, defined as the weight of explosive, in kg, per cubic meter of rock; *Q* is the mass, in kg, of the explosive in the hole; and *RWS* is the weight strength relative to ANFO (115 is the RWS of TNT).

The role of the Rosin Rammler equation is to estimate the complete fragmentation distribution. For a given mesh size or screen opening, *X*, this equation is able to estimate the percentage of fragments retained. It is given as[22]:

Equation 4

$$R_x = \exp^{-}\left(\frac{X}{X_c}\right)^{n}$$

where R_x is the proportion of fragments larger than the mesh size *X* (cm), and X_c is the characteristic fragment size (cm). The characteristic size is one through which 63.2% of the materials pass. If the characteristic size and the uniformity index are known, a size distribution curve can be plotted for the rock fragments[18]. The curve is plotted as percentage passing vs. mesh size. The former is obtained by subtracting R_x from one. **Equation 4** can be rewritten to make direct use of the mean fragment size, X_{50}, as follows[20,21]:

Equation 5

$$R_x = \exp^{-0.693}\left(\frac{X}{X_{50}}\right)^{n}$$

From **Equations 4** and **5**, the characteristic size can be deduced as:

Equation 6

$$X_c = \frac{X_{50}}{0.693^{\frac{1}{n}}}$$

The third part of the Kuz-Ram model is the uniformity index, developed by Cunningham through several investigations which involved consideration of the effects of blast geometry, hole diameter, burden, spacing, hole length, and drilling accuracy[4]. This equation is given as[20,21]:

Equation 7

$$n = \left(2.2 - \frac{14B}{d}\right)\sqrt{\left(\frac{1+\frac{S}{B}}{2}\right)}\left(1 - \frac{W}{B}\right)\left(abs\left(\frac{BCL - CCL}{L}\right) + 0.1\right)^{0.1}\frac{L}{H}$$

where *B* is the burden (m); *S* is the spacing (m); *d* is the hole diameter (mm); *W* is the standard deviation of drilling precision (m); *L* is the charge length (m); *BCL* is the bottom charge length (m); *CCL* is the column charge length (m); and *H* is the bench height (m). **Equation 7** is multiplied by 1.1 when using a staggered pattern. The value of *n* is essential in determining the shape of the size distribution curve, and is usually between 0.7 and 2. High values indicate uniform sizing, while low values indicate a wide range of sizes, including both oversize and fines[18,23]. **Equations 3, 5** and **7** are what constitute the typical Kuz-Ram model.

Cunningham[2] makes modifications in the model twenty years on, mainly as a result of the introduction of electronic delay detonators. This leads to what is now known in the literature as the modified Kuz-Ram model. The adjustments by Cunningham incorporate the effects of inter-hole delay and timing scatter. The changes also incorporate correction factors for the rock factor and uniformity index. These changes lead to the modification of **Equations 3** and **7** as follows[2]:

Equation 8

$$X_{50} = AA_TK^{-0.8}Q^{\frac{1}{6}}\left(\frac{115}{RWS}\right)^{\frac{19}{20}}C(A)$$

Equation 9

$$n = n_s\sqrt{\left(2 - \frac{30B}{d}\right)}\sqrt{\left(\frac{1+\frac{S}{B}}{2}\right)}\left(1 - \frac{W}{B}\right)\left(\frac{L}{H}\right)^{0.3}C(n)$$

where A_T is a timing factor for the effect of inter-hole delay, *C(A)* is a correction factor for the rock factor, n_s is the uniformity factor for the effect of timing scatter, and *C(n)* is a correction factor for the uniformity index. Thus, the modified Kuz-Ram model comprises **Equations 5, 8** and **9**.

A major shortfall of the Kuz-Ram model is the underestimation of fines. Extensions to the model have, thus, emerged with the objective of improving the prediction of fines. The CZM and TCM are such models[18]. Kanchibotla, Valery, and Morrell [24] address the issue of fines via the CZM model, which provides fragment distribution based on the coarse and fine parts of the muck pile. The authors note that during blasting, two different mechanisms control rock fragmentation, i.e., tensile fracturing and compressive-shear fracturing. Tensile fracturing produces coarse fragments, while compressive fracturing produces the fines. The model predicts the coarser part of the size distribution using the Kuz-Ram model. The size distribution of the finer part is predicted by modifying the values of *n* and X_c in the Rosin-Rammler equation. Djordjevic[25] develops a two-component model (TCM) based on the same mechanisms of failure captured by Kanchibotla *et al.*[24] in their work. The model utilizes experimentally determined parameters from small-scale blasting, and parameters of the Kuz-Ram model to obtain an improved prediction of fragment size distribution.

Ouchterlony[26] develops the KCO model which ties in the Kuz-Ram, CZM, and TCM models. The KCO model replaces the original Rosin-Rammler equation with the Swebrec function to predict rock fragment size distribution. The replacement stems from the author's recognition that the Rosin-Rammler curve has limited ability to follow the various distributions from blasting. The Swebrec function proves to be more adaptable and is able to predict fines better. The model is given by **Equations 10** and **11** as follows[26]:

Equation 10

$$P(x) = \frac{1}{[1 + f(x)]}$$

Equation 11

$$f(x) = \left[\frac{\ln\left(\frac{X_{max}}{X}\right)}{\ln\left(\frac{X_{max}}{X_{50}}\right)} \right]^b$$

where $P(x)$ is the percentage of fragments passing a given mesh size, X; X_{max} is the upper limit of fragment size; X_{50} is the mean fragment size; and b is the curve undulation parameter. Just like the Rosin-Rammler model, the Swebrec function has the mean fragment size (X_{50}) as its central parameter but introduces an upper limit to fragment size (X_{max}). While the aforementioned extensions to the Kuz-Ram model improve the distribution of fines, they introduce yet another factor into a predictive model that is already somewhat extended[2].

With the advancement in computational power, attention is being drawn to the use of machine learning (ML) in rock fragmentation prediction. Over the last decade, researchers have used multivariate regression (MVR) analysis, artificial neural network (ANN), and support vector regression (SVR) to predict fragment size distribution. In their work, Hudaverdi, Kulatilake, and Kuzu[27] use MVR analysis to develop prediction equations for the estimation of the mean particle size of muck piles. They develop two different equations based on rock stiffness. The equations incorporate blast design parameters (i.e., burden, spacing, bench height, stemming, and hole diameter) expressed as ratios, explosives parameters (i.e., powder factor), and rock mass properties (i.e., elastic modulus and *in situ* block size). Comparative analysis involving results of the prediction equations, Kuznetsov empirical equation, and the actual values prove the capability of the proposed models in offering satisfactory results. The authors make use of a diverse database (the largest ever used in research at the time) representing blasts conducted in different parts of the world. This makes their prediction models robust to a wide range of blast design parameters and rock conditions.

Building upon the work of Hudaverdi *et al.*[27], Kulatilake *et al.*[5] developed MVR and ANN models for the same set of data used in the former authors' work. The authors train a single hidden layer neural network model to predict the mean particle size for each of two groups of data, as distinguished by the rock stiffness. The authors perform extensive analysis to determine the optimum number of neurons for the hidden layer. Comparative analysis reveals that the MVR and ANN models perform better than the conventional Kuznetsov model. Shi *et al.*[9] build upon the work of Kulatilake *et al.*[5] by exploiting the potential of using support vector regression (SVR) for predicting rock fragmentation. Using the same data set as the previous authors, Shi *et al.*[9] develop an SVR model for predicting mean fragment size. They compare the results of the SVR model with those of ANN, MVR, Kuznetsov, and the actual values. The comparison shows that SVR is capable of providing acceptable prediction accuracy.

The effectiveness of prediction models is assessed via comparative analysis involving post-blast measurement. Post-blast measurement techniques have been developed over the years for determining the true fragment size after a blast was completed. An accurate predictive model will record insignificant deviation from the true fragment size. The available techniques for measuring fragmentation output can be classified as direct and indirect[3]. The direct methods include sieve analysis, boulder count, and direct measuring of fragments. The most accurate method of determining fragmentation is to sieve the whole muck pile. However, because muck piles are large, the use of sieving and the other direct methods can be tedious, time-consuming, and costly[5]. Thus, they are not practicable for muck pile fragment distribution. They can, however, be used for smaller amounts of fragment materials, and for very special purposes[3].

The indirect methods of fragment size measurement include digital image processing, and measurement of parameters, which can be correlated to the degree of fragmentation[3]. Digital image processing involves the use of sophisticated software and hardware for measuring fragment size. It is the latest fragmentation analysis tool and has largely replaced the conventional methods. The use of this tool comprises the following steps: image capturing of muck pile, image scaling, image filtering, image segmentation, binary image manipulation, measurement, and stereometric interpretation[5]. Though quick and cost-effective, this tool has some challenges. Non-uniform lighting, shadows, and a large range of fragment sizes can make fragment delineation very difficult. Another challenge is the overestimation of fines since the computer treats all undigitized voids between the fragments as fines. Thus, to obtain accurate estimation, a correction must be applied. Additionally, the wide variations in size may require different scales of calibration[5,28].

DATA AND METHODOLOGY

This section discusses the data and methods employed in this study. The data set comprises 102 blasts. Using this data set, we develop a multilayered artificial neural network and support vector regression models that satisfactorily predict mean rock fragment size.

Data Source and Description

The data set used in this work is obtained from the blast database compiled by Hudaverdi *et al.*[27], and subsequently used by Kulatilake *et al.*[5] and Shi *et al.*[9]. The compilation consists of blast data from various mines around the world. The data, therefore, represents a diverse range of blast design parameters and rock formations. Having such a diverse range of data is good for the purpose of this study, i.e., training machine learning models for prediction. The implication here is that the predictive ability of the ensuing models would span a wide variety of rock formations. The compilation by Hudaverdi *et al.*[27] represents one of the largest and most diverse blast data collections in the literature, and thus fits the purpose of this study.

Table 1 shows a sample of the data. A summary of the individual research projects from which Hudaverdi *et al.*[27] compiled the data is provided hereafter. Blasts with labels "Rc", "En", and "Ru" are from research by Hamdi, Du Mouza, and Fleurisson[29], and Aler, Du Mouza, and Arnould[30] at the Enusa and Reocin mines in Spain. The Enusa Mine is an open-pit uranium mine in a schistose with moderate to heavily folded formation. The Reocin Mine is an open pit and underground zinc mine. Blasts designated

Table 1. Sample blast data[5,9,27,28,29,30,31,32,33].

ID	S/B	H/B	B/D	T/B	Pf ($\frac{kg}{m^3}$)	X_b (m)	E (Gpa)	X_{50} (m)
En1	1.24	1.33	27.27	0.78	0.48	0.58	60	0.37
En2	1.24	1.33	27.27	0.78	0.48	0.58	60	0.37
En3	1.24	1.33	27.27	0.78	0.48	1.08	60	0.33
Rc1	1.17	1.5	26.2	1.08	0.33	0.68	45	0.46
Rc2	1.17	1.5	26.2	1.12	0.3	0.68	45	0.48
Rc3	1.17	1.58	26.2	1.22	0.28	0.68	45	0.48
Mg1	1	2.67	27.27	0.89	0.75	0.83	50	0.23
Mg2	1	2.67	27.27	0.89	0.75	0.78	50	0.25
Mg3	1	2.4	30.3	0.8	0.61	1.02	50	0.27
Ru1	1.13	5	39.47	1.93	0.31	2	45	0.64
Ru2	1.2	6	32.89	3.67	0.3	2	45	0.54
Ru3	1.2	6	32.89	3.7	0.3	2	45	0.51
Mr1	1.2	6	32.89	0.8	0.49	1.67	32	0.17
Mr2	1.2	6	32.89	0.8	0.51	1.67	32	0.17
Mr3	1.2	6	32.89	0.8	0.49	1.67	32	0.13
Db1	1.25	3.5	20	1.75	0.73	1	9.57	0.44
Db2	1.25	5.1	20	1.75	0.7	1	9.57	0.76
Db3	1.38	3	20	1.75	0.62	1	9.57	0.35
Sm1	1.25	2.5	28.57	0.83	0.42	0.5	13.25	0.15
Sm2	1.25	2.5	28.57	0.83	0.42	0.5	13.25	0.19
Sm3	1.25	2.5	28.57	0.83	0.42	0.5	13.25	0.23
Ad1	1.2	4.4	28.09	1.2	0.58	0.77	16.9	0.15
Ad2	1.2	4.8	28.09	1.2	0.66	0.56	16.9	0.17
Ad3	1.2	4.8	28.09	1.2	0.72	0.29	16.9	0.14
Oz1	1	2.83	33.71	1	0.48	0.45	15	0.27
Oz2	1.2	2.4	28.09	1	0.53	0.86	15	0.14
Oz3	1.2	2.4	28.09	1	0.53	0.44	15	0.14

"Mg" are from a study by Hudaverdi[31] at the Murgul Copper Mine, an open-pit mine in northeastern Turkey. Those designated "Mr" are from a study by Ouchterlony *et al.*[28] at the Mrica Quarry in Indonesia. The rock formation is mainly andesite. Blasts with the "Sm" label are from an open-pit coal mine in Soma Basin, in Western Turkey[32]. Blasts labeled "Db" are from the Dongri-Buzurg open-pit manganese mine in Central India. The rock formation is generally micaceous schist and muscovite schist[33]. Blasts labeled "Ad" and "Oz" are, respectively, from the Akdaglar and Ozmert quarries of the Cendere basin in northern Istanbul. Rock formation at both quarries is sandstone[27].

The data set features blast design parameters that can be categorized as geometric, explosives, and rock parameters. The geometric parameters include burden, B (m), spacing, S (m), stemming, T (m), hole depth, H (m), and hole diameter, D (m). These are represented in the data set as ratios and include hole depth to burden (H/B), spacing to burden (S/B), burden to hole diameter (B/D), and stemming to burden (T/B) ratios. The powder factor, Pf (kg/m^3), represents the explosives parameter and shows the distribution of explosives in the rock. The elastic modulus, E (GPa), and the *in situ* block size, Xb (m), represent the rock parameters. Specifically, *in situ* block size represents the rock mass structure, while the elastic modulus represents the intact rock properties[27]. In effect, a total of seven rock fragment size prediction parameters are in the data set, and these will constitute the input parameters (independent variables) for the SVR and ANN models. The data set also features a post-blast parameter, i.e., X_{50}(m), which is the actual mean fragment size. This will be the output parameter (dependent variable) to be predicted by the models. **Table 2** shows the summary statistics of the seven input parameters and the mean fragment size for the entire data set.

Model Development

Support vector regression (SVR) and artificial neural network (ANN) models are built for a total of 102 blasts. We split the data into training and test sets comprising 90 and 12 blasts, respectively. The test set has Kuznetsov predictions matching the actual fragment size. This is for the purpose of comparative assessment of results. The data set is scaled within the range 0-1 since the parameters have different orders of magnitude. The scaling is performed using the MinMaxScaler function of the Scikit-learn Python library. The SVR and ANN models are built using the Scikit-learn and Keras Python libraries, respectively[34,35].

SVR Modeling

Using Scikit-learn, we develop and train a support vector regression model for prediction. The modeling process involves iterating over several combinations of the following

Table 2. Summary statistics.

Variable		Minimum	Maximum	Mean	Standard Deviation
Input	S/B	1	1.75	1.20	0.11
	H/B	1.33	6.82	3.46	1.60
	B/D	17.98	39.47	27.23	4.91
	T/B	0.5	4.67	1.27	0.69
	Pf (kg/m^3)	0.22	1.26	0.55	0.24
	X_b (m)	0.29	2.35	1.16	0.48
	E (Gpa)	9.57	60	30.18	17.52
Output	X_{50} (m)	0.12	0.96	0.31	0.18

support vector hyper-parameters: regularization (C), epsilon (ε), and kernel (k). Four kernels are considered for modeling, i.e., radial basis function (rbf), polynomial (poly), sigmoid, and linear. Twenty-five different values of C are considered in the interval [1:10], and twenty-seven different values of ε are considered in the interval [1×10−6:0.3]. This yields a total of 2700 combinations of hyper-parameters, each representing a unique SVR model. The process of searching for the optimal combination of these hyper-parameters (adjustable parameters which control the support vector) is known as hyper-parameter tuning. To aid with this process, the GridSearchCV function in Scikit-learn is used[34]. It involves building SVR models using each of these hyper-parameter combinations and subsequently using cross-validation to assess model performance. We adopt the five-fold cross-validation technique. This means that for each hyper-parameter combination, the data are split into five folds. The hyper-parameter combination undergoes five runs of model training, and during each run, a distinct fold (one-fifth of the training data) is set aside for validation purposes. The final score assigned to the hyper-parameter combination is the average validation score from the five runs. This process is repeated for all other hyper-parameter combinations. We retrieve the best performing combination of hyper-parameters, and these are C = 5.25, ε = 0.04, and kernel = rbf. The final SVR model is thus built using these hyper-parameters.

In this study, retrieval of the best performing combination is based on the mean squared error (MSE) scoring metric. The MSE is a statistical metric that provides a means of assessing performance between two or more models. For each model, the MSE measures the average squared difference between the actual and predicted values. A perfect model would yield an MSE of zero, signifying that the actual values are perfectly predicted by the model, i.e., there is no error in prediction. In machine learning, the best-performing model among alternatives will be the one with MSE closest to zero. We show the MSE values for selected hyper-parameter combinations for the training and test data in **Figure 3**. From the figure, we observe that models with rbf kernels have better generalization abilities in respect of unseen, real-world data, i.e., data not included in the training process. This is represented by the test data. The best-performing model retrieved from the hyper-parameter tuning is of the rbf kernel type. It yields the lowest MSE value for the test data.

ANN Modeling

Using Keras, we develop a variety of multilayered ANNs with up to four hidden layers for prediction. In each instance, hyper-parameter tuning is performed to obtain an optimal number of neurons (units) for the hidden layers under consideration. In all cases, the input and output layers have fixed neurons, being seven and one, respectively. These represent the seven input parameters, and the output parameter (X_{50}), which we seek to predict. **Figure 4** is a schematic representing the general architecture of the ANNs used in this study.

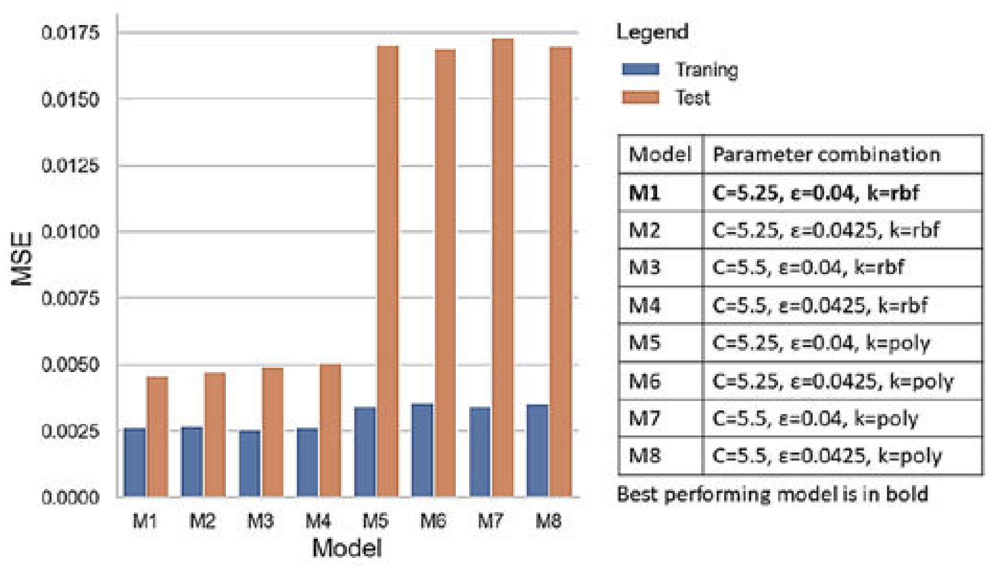

Figure 3: MSE plot for selected SVR hyper-parameter combinations.

For each instance of hidden layers, hyper-parameter tuning is performed using the Bayesian optimization object in Keras[35]. The process involves iterating over several combinations of neurons for a given instance of hidden layers and returning the combination that yields the best performance. This process can be very cumbersome and time-consuming when carried out manually. The use of Bayesian optimisation saves time by automating the search process for the best combination of neurons for a given number of hidden layers. During the search process, 20% of the training data is set aside for validation purposes using the MSE scoring metric. The remaining data are used for training, and this involves running 1500 epochs to yield an acceptable reduction in prediction error.

Table 3 shows the results for the various hidden layers considered. For each instance of hidden layers, the table shows the optimal number of neurons returned via hyper-parameter tuning. The neural network with four hidden layers is selected as the final ANN model. This is based on the test scores, which represent the ability of the models to generalize to unseen, real-world data. The four-hidden-layer architecture has the lowest test score.

In the second configuration of hidden layers, the batch normalization (BN) technique serves to control model overfitting, so as to improve model generalization in respect of unseen, real-world data. Batch normalization applies a transformation that maintains the mean output close to zero and the output standard deviation close to 1, thereby standardizing the inputs to a given layer[35]. We show the performance of selected hyper-parameter combinations for the various hidden layer instances in **Figure 5**. The figure shows how the final ANN model (M8) compares with other models from the hyper-parameter tuning exercise. Model M5 has the worst generalization performance while model M8 has the best generalization performance.

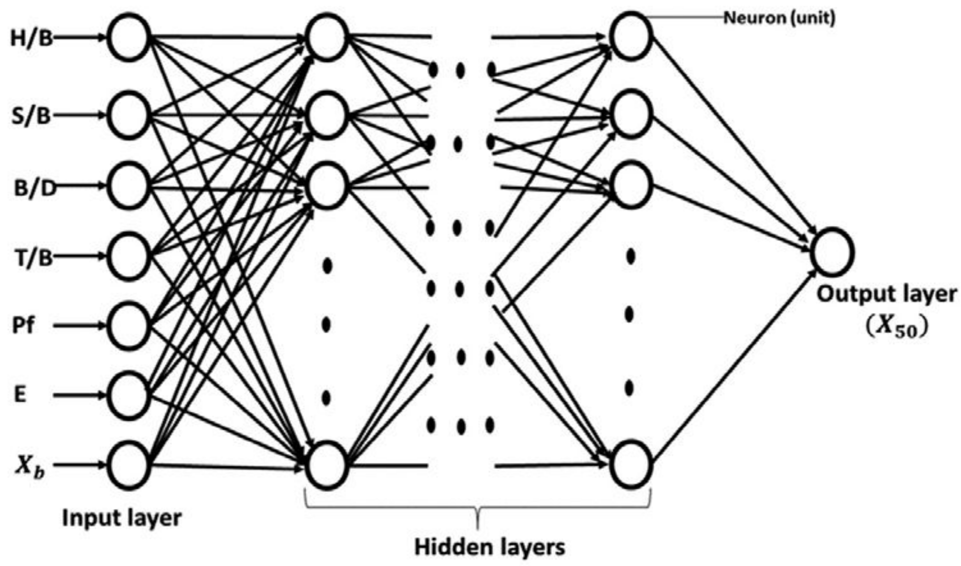

Figure 4: ANN architecture for rock fragmentation prediction.

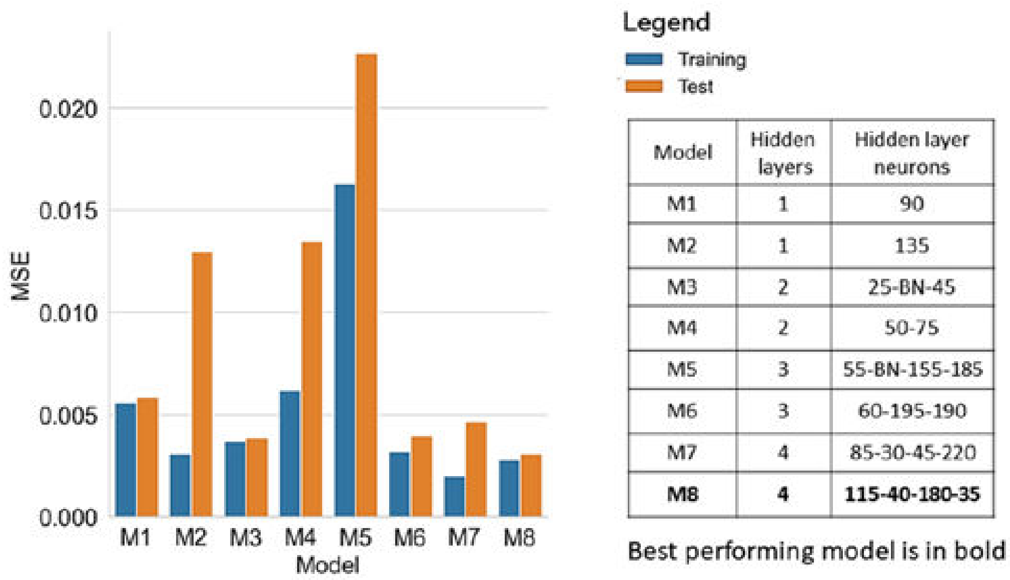

Figure 5: MSE plot for selected ANN hyper-parameter combinations.

Table 3. Optimal neurons for hidden layers.

Number of Hidden Layers	Optimal Neurons for Hidden Layers	MSE for Test Data	Selected Model
1	90	0.0059	
2	25-BN-45	0.0039	
3	60-195-190	0.0040	
4	115-40-180-35	0.0031	✓

Table 4: Model performance.

Model	Mean Squared Error (MSE)	
	Training	Test
SVR (C=5.25, ε = 0.04, kernel = rbf)	0.0026	0.0044
ANN (115-40-180-35)	0.0028	0.0031

RESULTS AND DISCUSSION

Through hyper-parameter tuning, we obtain the final SVR and ANN models. For the purpose of assessing model generalisation, we subject these models to testing. The test data set comprises 12 blasts; these are not used for training. The performance of the model on this data shows how well it will perform when deployed in the real world. **Table 4** shows the performance of the final models on the training and test sets using the mean squared error (MSE) as a scoring metric.

For the purpose of comparative assessment, the Kuznetsov empirical technique, i.e., **Equation 3**, is used to predict the mean rock fragment size for the test data.

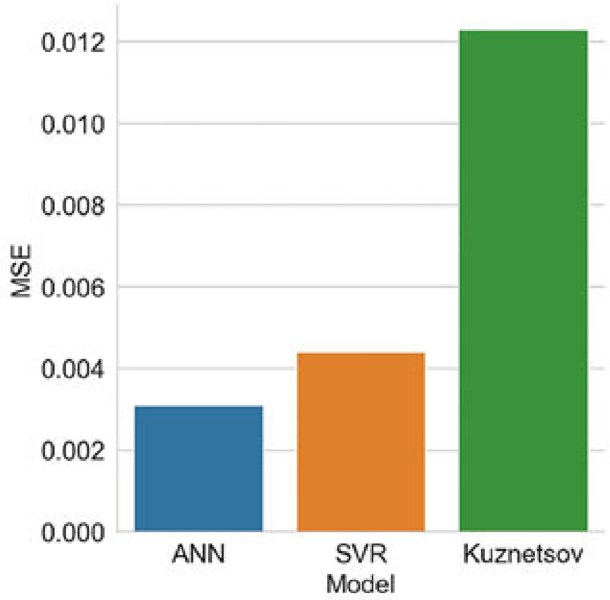

Figure 6: MSE plot for test data.

Test results obtained for the ANN and SVR models are compared with those for the Kuznetsov technique and the actual values. **Table 5** and **Figure 6** show the results for all three modeling techniques. It is observed that the ANN model records the least error while the Kuznetsov records the highest error. The coefficient of determination (r2) measures the proportion of the variation in the dependent variable (mean fragment size) that is accounted for by its relationship with the independent variables. It ranges between zero and one. A model with r2 closer to one is said to be reliable in predicting the dependent variable. The foregoing indicates that the ANN and SVR models are better able to model the relationship between the dependent and independent variables than the Kuznetsov empirical model. They show superior performance to the Kuznetsov as a result of their inherent ability to model complex, nonlinear relationships, such as exist between rock fragment size and blast design parameters.

Table 5: Results for test data.

Blast Number	Mean Fragment Size (m)			
	Actual	Predictions		
		ANN	SVR	Kuznetsov
1	0.47	0.44	0.38	0.48
2	0.64	0.68	0.64	0.71
3	0.44	0.38	0.41	0.42
4	0.25	0.25	0.25	0.33
5	0.20	0.15	0.14	0.27
6	0.35	0.21	0.52	0.09
7	0.18	0.19	0.19	0.38
8	0.23	0.17	0.18	0.22
9	0.17	0.17	0.19	0.25
10	0.21	0.21	0.20	0.12
11	0.20	0.21	0.19	0.13
12	0.17	0.24	0.26	0.23
Coefficient of determination (r^2)		0.87	0.81	0.58

CONCLUSIONS AND FUTURE WORK

The paper successfully demonstrates the potential of achieving higher accuracy in mean rock fragment size prediction using multilayered artificial neural network (ANN) and support vector regression (SVR). Using varied blast data sets from different parts of the world, we obtain training and test sets comprising 90 and 12 blasts, respectively, for building multilayered ANN and SVR models. Both models perform satisfactorily and better than the conventional Kuznetsov empirical model. The paper further demonstrates the possibility to analyze a varied number of hidden layers for a neural network in a less cumbersome way using Keras. Keras makes it less time-consuming to consider the performance of a wide variety of hidden layers and neurons via the Bayesian optimization feature. Thus, multilayered ANN analysis of rock fragmentation, which is typically time-consuming, can be carried out in a relatively shorter time. The end goal here is that blasting engineers would be able to fully exploit the potential of the multilayered ANN architecture for improved performance without having to do manual hyper-parameter tuning. The trained ANN and SVR models could be incorporated into existing fragmentation analysis software to give blasting engineers more accurate options for mean rock fragment size estimation. This incorporation would make it possible for blasting engineers to have access to results from both empirical and machine learning techniques. Blasting engineers would then be able to conduct post-blast analysis to verify the improved accuracy offered by the machine learning techniques. Commercial fragmentation software providers could adopt this integrated approach to gradually build client confidence in the use of machine learning techniques with time.

In the future, we seek to improve model performance via data augmentation. We intend to do this using the variational autoencoding (VAE) technique. VAE is a deep learning technique that fits a probability distribution to a given data set, and then samples from the distribution to create new unseen samples. Thus, the VAE offers a means of augmenting the data set used in this study to improve model training, and thus enhance pattern recognition and prediction. We also seek to build additional rock fragmentation models using other machine learning techniques. The final phase of this project will involve developing robust machine learning-based fragmentation software that will not only predict the mean fragment size but the entire fragment size distribution.

Please note that references and reading can be obtained using the following link: https://www.mdpi.com/2673-6489/2/2/13

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Industrial explosives market to surpass US$ 22,491.5m Million by 2033

The mining industry is poised on the threshold of some exciting opportunities. It has been realized that the unit operations such as drilling, blasting, excavation, loading, hauling and crushing are interrelated variables in the total cost equation. The development, advancement and utilization of the innovative technologies are very important for the mining industry to be cost effective In order to improve performance, the drilling and blasting industry is rapidly adopting technology in all forms. In the modern mines it is very common to encounter the latest forms of laser measurement technologies, global positioning systems (GPS), communication technology and computer systems. The developments in the areas of planning and design of blasts, drill monitoring, drillhole deviation, drill machine navigation systems and laser profiling systems are currently being used within the mining sector.

XPLOSIVES MANUFACTURING PROCESS

The explosives manufacturing process involves several steps to ensure safety and effectiveness. It typically begins with the selection and preparation of raw materials, followed by mixing and blending them to create a homogeneous mixture. This mixture is then shaped into the desired form, such as pellets or sticks. Next, the explosives are subjected to a curing process to enhance stability and performance. Finally, quality control measures are implemented to ensure compliance with safety regulations and standards. The entire process requires strict adherence to safety protocols and expertise in handling hazardous materials. An explosive (or explosive material) is a reactive substance that contains a great amount of potential energy that can produce an explosion if released suddenly.

The 3 fundamental types of explosives are mechanical, chemical and nuclear. A mechanical explosive is one that depends on a physical reaction such as overloading a container with compressed air, a mechanical device is often used in mining where a chemical reaction is undesirable.

A chemical explosive is a mixture that when subjected to heat, impact, friction, or detonation, it undergoes a rapid chemical change, involving large volumes of heated gases that exert pressure on a surrounding medium. A nuclear explosive is a device that from a nuclear reaction, releases a vast amount of energy that causes an explosion.

The 3 types of explosives that we will be focusing on are:

- Blasting and bulk explosives – an emulsified Ammonium Nitrate solution incorporating a fuel phase. Typically used for commercial blasting applications.
- Perforating explosives – intended for use in the oil and gas well industry, perforating guns carry explosive-shaped charges downhole, where they are detonated to create tunnels that act as conduits through which reservoir fluids flow from the formation.
- Special-application explosives – high explosives used for other applications, including primary explosives.

USES AND WHY WE NEED THEM

In recent years, the largest commercial application of explosives is mining, which has increased their usage in surface and underground mines. Whether the mine is on the surface or buried underground, blasting explosives are the most cost-effective way of displacing a large volume of material. Emulsion explosives have a lot of great advantages including safety and security, excellent resistance to water, increased velocity of detonation, transport, handling and storage, savings in drilling operations and low gas emissions.

The mining industry tends to use nitrate-based explosives such as emulsions of fuel oil and ammonium nitrate solutions, mixtures of ammonium nitrate prills (fertilizer pellets) and fuel oil (ANFO) and gelatinous suspensions or slurries of ammonium nitrate and combustible fuels.

Many factors contribute to increased sales of emulsion explosives. Developing countries are constantly on the quest towards rich materials through mining and quarrying. On the other hand, infrastructure projects like underground railways, road tunnels and construction projects all favour market growth.

PRODUCTION OF EXPLOSIVES

Emulsion Explosives have been commercially available for over 50 years now and during this period, their popularity and production have been increasing year after year. In the process of manufacturing emulsion explosives, two basic pre-mixes are formed. The first comprises an aqueous solution of inorganic oxidizing salts, and the second, hydrocarbon fuel components, which provide the oil phase of the water-in-oil emulsion.

The unique feature of EE makeup is that they are insensitive to initiation and cannot sustain detonation without being sensitised. Due to this classification, the requirements for transporting EE matrices are much less stringent than the requirements for transporting traditional energetic materials. The simplistic transportation of emulsion explosives was the key factor underlying the development of bulk emulsion explosives.

WORLD GROWTH IN EMULSION EXPLOSIVES

India

The emulsion explosives market in India is expected to rise by 5.7% by 2028. A vast number of open mines in India use bulk emulsion explosives, with an annual use of around 550,00 tons per year. Some of the major projects in India include Transalpine railway tunnels and roads, and dams for hydroelectric power plants and power stations, with the number of major projects increasing year on year. The country's emulsion explosives value is expected to reach over $159m by 2028.

United States

Compared with India, the US is expected to rise at a steady rate by 2028, with around a 4.7% year-on-year growth by volume. This is mainly due to the country already being a leader in the market, so it is hard to achieve such growth. North American explosives producers are now looking at opportunities in the Latin American market, as there is a strong presence of precious metals such as lithium, silver and copper. This attracts significant investment from international mining companies, which is expected to increase demand for Bulk emulsion explosives.

China

The demand for emulsion explosives in China is expected to increase by a massive 6.2% by 2028, with the Chinese mining industry playing a substantial role in the Chinese economy. This is due to China being the world's leading producer of steel, coal, aluminium, lead, rare earths, tin, zinc, tungsten and magnesium and other metallic minerals. The country's emulsion explosives value is expected to reach over $262m by 2028.

CHALLENGES

Transportation
NG dynamites possess poor safety properties during their manufacture transportation and use. For example, the use of dynamites is diminishing with time. Safer explosives such as emulsion explosives are gradually replacing them.

Volatility
Volatility is the readiness with which a substance vaporizes. Excessive volatility often results in the development of pressure within rounds of ammunition and the separation of mixtures into their constituents. Volatility affects the chemical composition of the explosive such that a marked reduction in stability may occur, which results in an increase in the danger of handling.

Toxicity
Many explosives are toxic to some extent. Manufacturing inputs can also be organic compounds or hazardous materials that require special handling due to risks. The products, residual products or gases that make up explosives can be toxic, whereas others are harmless.

Structural Collapse
Using explosives when mining can cause a risk of entrapment following the collapse of a structure. Measures must be put in place to try and mitigate this risk and plans should be in place should this eventuality arise.

THE FUTURE OF EXPLOSIVES

The mining explosives industry's development rate has been significantly boosted by the surging demand for minerals and metals worldwide. Mining explosives are widely used in metal mining, quarrying, non-metal mining, and coal mining applications. Coal mining is one of the most important applications of mining explosives.

The accelerated use of coal as well as rare earth metals such as silver and gold along with earth minerals like bauxite and iron ore in diverse industries like chemical, automotive, and thermal will foster the need for extremely potent explosive products.

New and modern explosives technologies are compatible with both augured and pumped loading techniques across wet, dewatered, and dry hole conditions. Companies active in the mining explosives industry are focusing on enhancing their research capacities to develop more innovative technologies that can let mining customers carry out operations more precisely and efficiently. The combination of modern digital technology, explosives delivery technology, and formulation chemistry is providing great leverage to mining customers.

Industrial explosives, crucial for mining and construction, transform rapidly into gases under trigger conditions. In the U.S., the construction sector is the largest consumer of these powerful blasting materials

In the most recent survey conducted by Persistence Market Research, the global industrial explosives market is currently enjoying a market valuation of US$ 12,324.6 Mn as of 2023, with a projected expansion at a Compound Annual Growth Rate (CAGR) of 6.2% from 2023 to 2033.

The market is expected to reach a substantial valuation of US$ 22,491.5 Mn by the conclusion of the forecast period.

The industrial explosives market sector has witnessed substantial growth in recent years, and this upward trend is expected to persist due to a heightened demand for blasting materials from the mining and construction sectors.

The Latin America and Africa regions are poised for significant growth, primarily attributed to increased investments in the mining industry.

Urbanization and population growth will provide numerous opportunities for current and emerging industrial and commercial entities, fostering growth throughout the projected period.

Market Scope:

Report Coverage	Details
Market Revenue 2023	US$ 12,324.6 million
Estimated Revenue 2033	US$ 22,491.5 million
Growth Rate - CAGR	6.2%
Forecast Period	2023-2033
No. of Pages	297 Pages
Market Segmentation	• Type • End Use • Region
Regions Covered	• North America • Europe • Latin America • East Asia • The Middle East & Africa • South Asia & Pacific
Key Companies Profiled	• Orica Limited • NOF Corporation • Enaex S.A. • African Explosives Limited • Dyno Nobel • Exsa S.A. • Maxam corp Holdings • Austin Powder Company • Irish Industrial Explosives Ltd • Ideal Industrial Explosives Limited • Sichuan Yahua Industrial Group Co., Ltd • BME Mining • Solar Industries • LSB INDUSTRIES • Eurenco S.A.

Market Growth Drivers:

Increased Investment in the Mining Industry: The surge in investment in the mining sector, particularly in regions like Latin America and Africa, is a significant driver for the industrial explosives market. These explosives play a crucial role in mining operations, contributing to increased demand.

Rising Demand from the Construction Industry: The construction industry's continuous growth and development contribute to the increased demand for industrial explosives. These materials are essential for activities such as quarrying and excavation in construction projects.

Urbanization and Infrastructure Development: The ongoing process of urbanization and infrastructure development worldwide creates a demand for industrial explosives in various construction and development projects. As cities expand and new infrastructure projects emerge, the need for these explosives grows.

Population Growth: Population growth, especially in developing regions, leads to increased demand for housing, infrastructure, and related construction activities. Industrial explosives are essential in the excavation and foundation preparation processes for such projects.

Technological Advancements: Continuous advancements in explosive technologies contribute to the efficiency and safety of industrial explosive products. Innovations in blasting techniques and explosive formulations enhance their effectiveness in various applications.

Market Restraints:

Stringent Regulatory Frameworks: Strict regulations and safety standards imposed by governments and regulatory bodies may pose challenges for the industrial explosives market. Compliance with safety measures can increase operational costs for manufacturers and end-users.

Environmental Concerns: Growing environmental awareness and concerns regarding the impact of explosive materials on ecosystems and air quality may lead to increased scrutiny and restrictions. This can result in the development and adoption of more environmentally friendly alternatives, impacting traditional explosive sales.

High Costs and Operational Risks: The costs associated with the manufacturing, storage, and transportation of industrial explosives can be substantial. Additionally, the operational risks involved in handling explosive materials can lead to increased insurance costs and adherence to stringent safety protocols.

Volatility in Raw Material Prices: The industrial explosives industry is sensitive to fluctuations in raw material prices, such as chemicals and minerals used in explosive formulations. Unpredictable changes in these prices can impact production costs and profit margins for manufacturers.

Global Economic Uncertainties: Economic uncertainties and downturns can affect industries dependent on construction, mining, and infrastructure development, leading to reduced demand for industrial explosives. The cyclical nature of these industries makes the market vulnerable to economic fluctuations.

Alternative Technologies: Advancements in alternative technologies, such as non-explosive demolition methods, may pose a challenge to the traditional industrial explosives market. Some industries may seek more sustainable and less hazardous alternatives for specific applications.

Opportunities:

Technological Advancements: Opportunities for innovation in explosive formulations and blasting technologies can enhance the efficiency, safety, and environmental sustainability of industrial explosives, opening new markets and applications.

Green Explosives and Sustainable Practices: Growing environmental concerns provide an opportunity for the development and adoption of "green" explosives that are more environmentally friendly. Manufacturers can focus on sustainable practices to meet evolving regulatory standards and market preferences.

Emerging Markets and Regions: Exploring and expanding into emerging markets and regions with increasing industrial activities, such as parts of Asia and Africa, can provide new avenues for growth. Rising investments in mining, construction, and infrastructure development in these areas offer significant opportunities.

Infrastructure Development Projects: The increasing focus on large-scale infrastructure projects, including transportation, energy, and urban development, presents opportunities for the industrial explosives market. These projects often require blasting materials for excavation and construction purposes.

Mining Exploration and Extraction: With the demand for minerals and metals continuing to rise, there are opportunities in providing explosives for mining exploration and extraction activities. New mining projects and expansions in existing mines create a demand for blasting materials.

COUNTRY-WISE INSIGHTS

How big is the opportunity for industrial explosives in China?

Despite initial concerns due to the global pandemic, the Chinese industrial explosives market is expected to grow by 7.5% annually in 2022. With China being the world's largest producer of coal and metal, the rapid expansion of its construction industry and increasing mining activities contribute to a significant surge in demand for industrial explosives. China is set to dominate both East Asian and global markets, accounting for about three-fourths of the market share in East Asia. Key Chinese companies are focusing on strategic changes, high-quality products, and after-sales services to boost overall demand.

How the mining sector is driving the Indian industrial explosives market?

India is a key player in the South Asian industrial explosives market, holding the largest share. High demand in coal mining and quarry sectors, coupled with rapid industrialization and being the second-largest global coal producer, is driving a 7.4% CAGR growth in the Indian industrial explosives market. Favorable policies and a thriving mining sector contribute to a conducive environment, offering significant opportunities in the global explosives market.

How are end-use industries of industrial explosives performing in the U.S.?

In the United States, the construction sector is the primary consumer of industrial explosives, representing the largest segment. The government's announcement of new construction projects during the forecast period is expected to drive increased demand for industrial explosives. The country is also witnessing widespread mining activities, contributing to rapid growth in the industrial explosives market. In 2021, U.S. miners produced approximately $90.4 billion worth of minerals, a significant increase from the $86 billion produced in 2020, according to the Geological Survey. These minerals are vital for manufacturing and trade, with many being used in common household products, leading to substantial demand.

How mining industries are solely dominating the consumption of industrial explosives?

The mining industry holds an 88% share in the global industrial explosives market, according to Persistence Market Research. Industrial explosives are crucial for mining activities, breaking through hard rocks beneath the earth's surface. The increasing demand for earth metals and minerals, coupled with government-supported exploration activities, is driving growth in the global mining sector. This growth is expected to significantly boost the demand for industrial explosives in the forecast period.

Why are bulk explosives experiencing a rise in demand?

Bulk explosives, comprising over 90% of the market share, experience high demand primarily due to their use in mining and detonation. These paste-form explosives are directly delivered to on-site working areas, with manufacturers handling the explosives themselves. The affordability of bulk explosives compared to packaged alternatives is another key factor driving their market demand.

KEY RECENT DEVELOPMENTS

Technological Advancements: Ongoing developments in explosive technologies, including advancements in formulations and blasting techniques, are enhancing the efficiency and safety of industrial explosives.

Sustainability Initiatives: Increasing focus on sustainable and environmentally friendly explosive formulations as part of industry-wide initiatives to address environmental concerns and regulatory requirements.

Market Expansion in Asia: Significant market growth in China and India, driven by expanding construction, mining activities, and infrastructure development, positioning these countries as key players in the global industrial explosives market.

Government Policies and Regulations: Implementation of new policies and regulations favouring the industrial explosives sector, creating a conducive environment for growth while ensuring safety and compliance.

Digitalization in Blasting Operations: Adoption of digital technologies and data analytics to optimize blasting operations, improving precision, efficiency, and overall performance in various applications.

Strategic Collaborations: Increased collaboration and partnerships among industry players, leading to strategic alliances, joint ventures, and technology-sharing agreements to enhance market presence and capabilities.

Focus on Safety and Training: Growing emphasis on safety measures, including training programs and consulting services, to address concerns related to the handling and usage of industrial explosives.

Rising Demand in the U.S.: In the United States, a surge in construction projects and widespread mining activities is contributing to increased demand for industrial explosives.

Some of the market players:

- Orica Limited: Orica is a global leader in the explosives and mining services industry, providing a wide range of products and solutions for mining, quarrying, and construction.

- NOF Corporation: NOF Corporation is a Japanese company engaged in the manufacturing and distribution of industrial explosives, specialty chemicals, and various related products.

- Enaex S.A.: Enaex is a Chilean company specializing in explosives and blasting services for the mining industry, offering a comprehensive range of products and solutions.

- African Explosives Limited: African Explosives Limited (AEL) operates in the explosives and chemical sectors, with a focus on providing blasting solutions for the mining and construction industries in Africa.

- Dyno Nobel: Dyno Nobel is a global explosives company offering innovative blasting solutions for the mining, quarrying, and construction industries, with a commitment to safety and sustainability.

- Exsa S.A.: Exsa S.A. is a leading explosives manufacturer based in Peru, pzroviding a diverse range of products and services for the mining and construction sectors.

- Maxam Corp Holdings: Maxam is a global technology company specializing in energetic materials and blasting solutions, serving various industries, including mining, defense, and civil engineering.

- Austin Powder Company: Austin Powder Company is a U.S.-based explosives manufacturer and distributor, offering a comprehensive range of products for the mining, quarrying, and construction industries.

- Irish Industrial Explosives Ltd: Irish Industrial Explosives Ltd is an explosives manufacturer based in Ireland, providing a range of blasting solutions for mining, quarrying, and infrastructure projects.

- Ideal Industrial Explosives Limited: Ideal Industrial Explosives Limited is an Indian company specializing in manufacturing and supplying industrial explosives for the mining and construction sectors.

- Sichuan Yahua Industrial Group Co., Ltd: Sichuan Yahua Industrial Group Co., Ltd is a Chinese company with diversified business interests, including the production of industrial explosives for mining and construction applications.

In recent times, the entire world of mining industry, including the biggest industrial explosive suppliers in India has seen a tremendous rise in the usage of emulsion explosives. The vital reason being the rise in demand for these explosives is its ease of adaptation, security, safety, resistance towards water, hassle-free storage, and many other more advantages that it offers as compared to all other explosives that are available in the market.

The industrial explosives company in India has always ensured that the emulsion explosives that they aim to sell hold all of their pumping properties and packaging stably throughout different temperatures. And since the explosives can hold it extremely well, they are stable, and the detonation properties can also be kept at a constant number even if the storage has been for a long time. And that is why the emulsion explosive suppliers India are so sure about its usage for surface mines along with underground mining.

According to a report from Future Market Insights, the global emulsion explosive market was evaluated at around US$ 2.4 billion in the year 2020. The important reason for soaring valuation is the high performance and enhanced safety guidelines provided for the emulsion explosives by the world players and the industrial explosive suppliers in India. Thus, here are a few critical reasons that why emulsion explosives have gained popularity among the mining players and how it hugely benefits surface mining projects.

EASY TO STORE AND TRANSPORT

Transport and storage play a key role in every kind of explosives. And the emulsion explosive suppliers India leave no stone unturned to offer the best quality storage and transportation services to their customers. Since the emulsion is categorized as an oxidizer, there is no danger when it comes to transportation and storage as it will never explode. The only time when an emulsion can turn into an explosive is when it is pumped into the borehole. The industrial explosive suppliers in India always recommend storing the emulsions between temperatures of -20 degrees to -50 degrees Celsius.

DIFFERENT DETONATION VELOCITY

Emulsion explosives have always been the most cost-effective and better choice when it comes to surface mining. The explosives are not only preferred by many experts but their low sensitivity to the mechanical stimulus makes them extremely popular. Apart from that, it can vary density through many ranges that result in varied detonation velocities. These emulsion explosives not only get the job done with their low impact but are also a safer option when it comes to protecting the environment as these explosives can be executed for medium to hard surface mining grounds.

WATER-RESISTANT

Without any doubt, the emulsion explosives are produced in such a way that even if there is water inside and outside, the boreholes can be filled up with the emulsion and nothing will happen to the entire operation as the emulsion are completely resistant to the water.

If the standard striking tests are being conducted, then be sure as the emulsion will not explode during the testing and remain stable. But there are chances of explosion if the emulsion comes in contact with the materials such as aluminum powder, detonators, or dynamites. In the end, these are explosives, and the blasting equipment suppliers pan India always advise to follow all the safety guidelines without fail.

Therefore, if you have the requirement for any type of emulsion explosives, then your attention must turn towards one of the finest and experienced emulsion explosive suppliers pan India SBL Energy Limited. This industrial explosives company in India has various ranges of emulsion packages explosives tailored as per your requirements which can be used for both surface and underground mining. Right from Cap sensitive Emulsion Large Diameter Cartridge Explosives (Booster/Primer Charge) to Booster sensitive Emulsion Large Diameter Cartridge Explosives, this industrial explosive supplier in India has everything that you need for your next project.

EXPLOSIVE NEW DEVELOPMENT IN SMALL-SCALE MINING

Researchers have developed software and technology to help small-scale mining operations conduct targeted rock blasting with minimal effort and impact on the environment.

There is currently no reliable solution to reduce the environmental impact of small-scale mines, especially considering that current mining technology relies on rock blasting and mobile mining equipment for loading and transportation. Some of this equipment uses the expensive and difficult to install Measurement While Drilling (MWD) system, which is inefficient for small scale mining operations.

The EU-funded SLIM project set out to develop cost-effective and more sustainable ways to blast and fragment rock using explosives in small-scale mining operations. Using advanced automatic blast design software, the SLIM project consortium focused on mitigating typical mining issues such as airborne particulate matter, vibrations and nitrate leaching. “The SLIM approach consists of injecting state of the art techniques into the mining operation by developing tools to control the excavation face, fine-tune the processing plant and reduce environmental effects, in order to improve feasibility, and profitability of mines, and gain public acceptance and trust,” says project coordinator José Sanchidrián.

A NEW GENERATION OF EXPLOSIVES

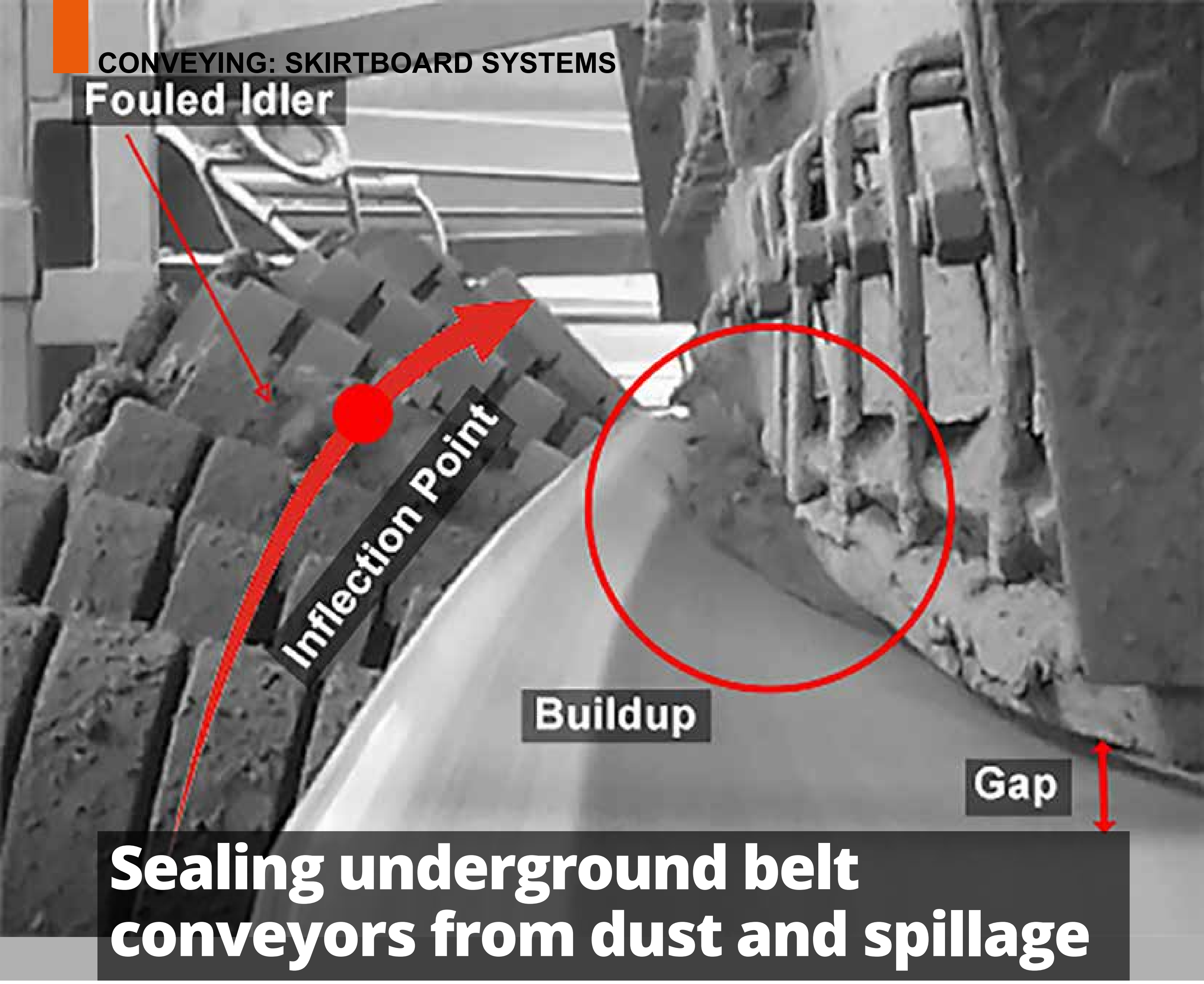
The SLIM team started by developing technologies capable of characterising explosives, identifying blasted rock fragments using artificial intelligence, and using systems that can predict the effect of certain explosives on specific rock types. SLIM developed a new generation of explosives and smart blast design software that can characterise rocks better than current systems and reduce the impact of rock blasting on the environment. This development is not only important for the European mining industry but for mining operations all over the world, to help them reduce economical costs and environmental impact such as groundwater contamination. The team experimented with, and developed, models to simulate how explosives would perform in mining operations, such as understanding rock fragmentation, the velocities, and the damage caused. Such information has already given mining operations the data they need to better understand and improve their overall performance by being as efficient as possible with minimal environmental impacts.

MWD USING LIDAR

SLIM developed and retrofitted a more cost-efficient Measuring While Drilling (MWD) system that uses the detailed analysis of photographs to predict the impact of explosives on target rock. In an effort to make mine planning smoother, the SLIM team created a system that uses light detection and ranging (LiDAR) to analyse rock damage and environmental impact after a blast, as opposed to the non-direct methods used currently. The SLIM team also developed a software that mitigates negative impacts such as fly rock or vibrations, and characterises the result of a blast, or the ‘muck hole’. “This software is important to improve the surface blasting work, as only reliable and correct assessments of blasting results improve mining operations,” Sanchidrián says.

REAL WORLD DATA FOR FURTHER DEVELOPMENT

Minera de Órgiva, a SLIM partner from Spain, used improved rock excavation technologies, and processing plant monitoring and control to nearly double its production at Sierra de Lújar mine. This enabled the profitable mining and processing of lower yielding ore – from a cutoff grade of nearly 40% fluorite to an expected cutoff of 20% by the end of the project. The result is more than a threefold increase in reserves and extending the working life of the mine by at least 50 years. “The SLIM project partners have accumulated an exceptional amount of data from laboratory and field trials and this dataset has a fundamental value in facilitating future research and development in the fields of explosives technology, rock blasting, performance assessment, and mining automation,” Sanchidrián concludes.



Sealing underground belt conveyors from dust and spillage

Sealing the on transition is impossible.

Any discussion around the best practices of "skirtboards as a system" must include elements of the entire loading zone as each element impacts the effectiveness of the skirtboards to perform well as a system. Placed on the transfer point of a belt conveyor involving the loading zone, settling zone, and stilling zone, the term skirtboard is derived from the early practice of using wooden boards to confine the load on conveyors.

Due to the punishing environment of underground operations and modern production demands, a skirtboard sealing system today consists of equipment – some permanent, some wear parts – that work in tandem to seal the conveyor loading area from dust emissions and fugitive fines. These innovative designs are engineered to improve workplace safety, reduce labor for cleanup and ensure efficient production.

DESIGN APPROACH

Conveyor design is an iterative process where initial selections are made for the belt width and speed based on the desired capacity and the path of the conveyor. The design approach depends upon the purchasing philosophy, lowest purchase price vs. lowest cost of operation.

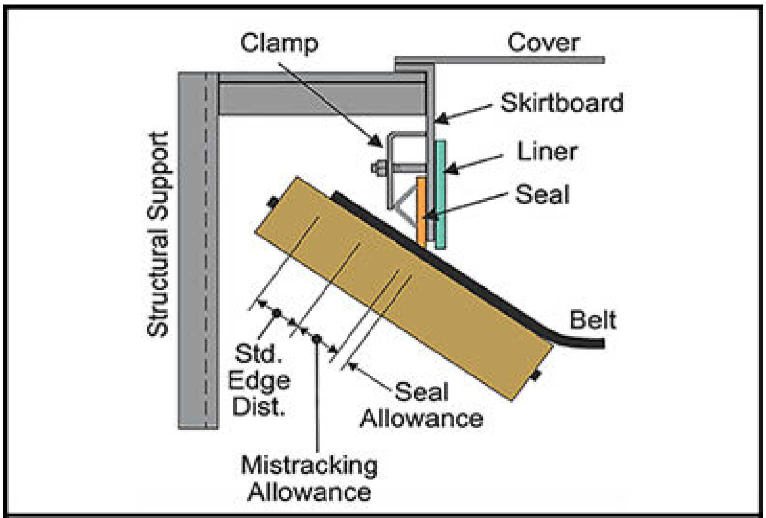
It is unusual to find a conveyor purchased on price alone meeting the specified throughput. Almost every conveyor is "upgraded" at some point, so provisions for the eventual increase in throughput and to address potential operating issues such as dust and spillage should be built into the design. Note that, one of the most common design shortcomings is lack of access for cleaning and maintenance.

SKIRTBOARD SYSTEM

The system includes the belt, tail pulley, loading chute, skirtboards, skirtboard covers, dust curtains belt support, sealing system and wear liners. It is recommended for the belt to be in reasonably good condition without existing skirtboard grooves, otherwise, the system may not seal the belt effectively. If dust is an issue, replacing enclosure covers after maintenance is an absolute must.

The material should be center loaded and the skirtboards aligned parallel to the centerline of the conveyor. Idlers that are not closely spaced under the skirtboard enclosure will make a bumpy belt path which leaves gaps between the skirt and the belt for dust and fines to escape. To produce a fully sealed environment, the belt should be supported with closely spaced idlers or belt support under the sealing system. If there are large lumps, an impact cradle should be used to support the belt and prevent damage.

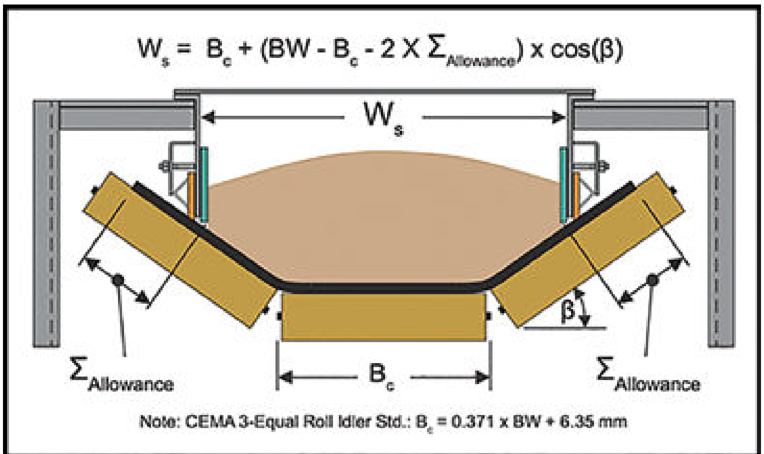
"Loading on the transition" is when the material is loaded as the belt is transitioning to a full trough angle. It is one of the main causes of grooving under the sealing system as it is impossible to seal the 3-dimensional belt surface in the transition even with adjustable wing idlers. The inflection point created at the first fully troughed idler creates an entrapment point for abrasive particles. Therefore, loading must only start after the belt is fully troughed to control fugitive material release and belt damage.



Skirtboard Sealing System Components

SKIRTBOARD WIDTH

There are various historical ratios for the spacing of skirtboards. They are usually based on belt width such as the Conveyor Equipment Manufacturers Association (CEMA) standard is 2/3 times or ½ times belt width for very free flowing material or multiple loading points. Another approach states 3 times the size of the largest average lump.



Skirtboard Width (actual requirements vs a generic rule)

The standard edge distance is an allowance to prevent material from falling from the belt as the edges sag between carrying idlers after the load zone. A mistracking allowance is the expected deviation of the belt path from the central axis of the conveyor. CEMA Misalignment Guide is based on the dimensions of standard CEMA idlers and pulleys and considers 3 categories of mistracking: Allowable, Actionable and Critical. [1] The International Organization for Standardization (ISO) misalignment allowance is +/- 40mm for belts up to and including 800 mm or +/- 5% (+/- 75mm max.) of the belt width for widths over 800 mm[2].

The free belt edge should be based on the thickness of the sealing system, skirtboards, wear liners and standard edge distance added together and measured along the troughed belt surface. This distance will determine the maximum skirtboard spacing. With a BW of 1200 mm, center roll width, Bc, of 452 mm, trough angle of 35 degrees, standard edge distance of 60 mm, a mistracking allowance of 100 mm and a sealing system 50 mm thickness, the skirtboard width inside the wear liners would be 757 mm. Note that this is the distance between skirtboards, not the distance between the wear liners, but wearliner thickness should be included.

SKIRTBOARD HEIGHT

The minimum skirtboard height is based on the maximum expected cross-sectional area contained between the skirtboards, so the belt's full edge-to-edge area should be used to determine the height of material rubbing on wearliners and to make sure the skirtboards are tall enough for a completely full belt. Use the loose bulk density – material before it settles on the conveyor – to represent the bulk density. The reason for this is the loose bulk density can be up to 40% less than the settled (vibrated) bulk density of the cargo on the carrying run, requiring the material cross-sectional area to be 40% greater at the point of impact until the load settles into a stable profile.

When a conveyor is purchased on price the skirtboards will typically be 300 mm tall to accommodate a basic vertical slab seal and clamping arrangement. With an engineered approach the height of the skirtboards is based on the above allowances and keeping the airspeed in the enclosure below 1.0 m/s. At this air speed, most nuisance dust will settle in the enclosure. When taking this approach, the quantity of air flowing through the enclosure is estimated by considering the displaced air from the initial loading, the induced air created by the separation of the material discharge stream drawing or

$$W_s = B_c + \left(BW - B_c - 2 \times Allowance\right) \times \cos(\beta)$$

$$B_c = 0.371 \times BW + 6.35\ mm\ \left[CEMA\ method\ or\ use\ actual\right] = 451.55\ mm$$

$$Allowance\ = 5\% \times BW + Mistracking\ Allowance + Sealing\ System\ Thicknes\ measured\ along\ belt\ surface\ = 210mm$$

$$\cos(35)\ = 0.9037$$

$$W_s = 451.55 \div (1200 - 451.55 - 2 \times 210) \times 0.9037\ = 757.4\ mm$$

Skirtboard structure can be unique to the operation and the application and should be determined by an experienced engineer.

Skirtboard structure can be unique to the operation and the application and should be determined by an experienced engineer.

inducing airflow into the transfer point and any generated air from prevailing winds or process equipment like crushers or screens[3].

For existing enclosures simply measure the average air speed at the exit. If the average speed is 3.0 m/s then the cross-sectional area of the enclosure needs to be three times the existing area (i.e. 3 times the height) to reduce the exit air speed to 1.0 m/s.

LENGTH OF SKIRTBOARDS

As with the width of the skirtboards there are various generic rules for the extended length of the skirtboards. The extension serves two purposes, first, it prevents spillage as the load settles into a stable profile after loading. Generic rules for containing turbulent flow range from 1.8 m extension past the dump point or, 1.5 m plus 1.2 m for every 1.0 m/s of belt speed. Secondly, the extension helps settle nuisance dust without extraction, so, 1.2 m per 1.0 m/s length for minor airflow and 1.8 m per 1.0 m/s length for major airflow is one recommendation for dust control.

THE LONGER THE ENCLOSURE, THE MORE TIME DUST HAS TO SETTLE, MAKING TO A CLEANER WORK ENVIRONMENT.

The ACGIH Industrial Ventilation manual provides guidance when collection is needed for respirable or hazardous dust. In general, it is good practice to make the extension generous in length and height, keeping in mind there is added friction from seals and material rubbing on the liners. This can be a significant additional load on the drive for long lengths of skirting. Material rubbing on the wear liners also creates drag so the capacity belt width and skirtboard spacing should consider minimizing material contact with the wearliners.

CONCLUSION

Designing an effective underground conveyor skirtboard system requires an iterative approach. Starting with basic capacity calculations ensures the belt is wide enough to accommodate the free belt edge, the sealing system, wear liners and expected mistracking allowance. Old design rules and fabricated solutions only work for the short term and often result in more maintenance. Installing a well-designed skirtboard sealing system for safety, ease of maintenance and less downtime is part of a cost-effective production plan with the greatest return on investment.

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R. Todd Swinderman
P.E. / President Emeritus / Martin Engineering

R. Todd Swinderman earned his B.S. from the University of Illinois, joining Martin Engineering's Conveyor Products division in 1979 and subsequently serving as V.P. and General Manager, President, CEO and Chief Technology Officer. Todd has authored dozens of articles and papers, presenting at conferences and customer facilities around the world and holding more than 140 active patents. He has served as President of the Conveyor Equipment Manufacturers' Association and is a member of the ASME B20 committee on conveyor safety. Swinderman retired from Martin Engineering to establish his own engineering firm, currently serving the company as an independent consultant.

European Metals flags potential improvements in delayed DFS

Dual-listed European Metals has delayed the publication of a definitive feasibility study (DFS) for the Cinovec lithium project, in Czech Republic.

However, chairperson Keith Coughlan expressed optimism recently, noting that the ongoing additional work held promise for significant project enhancements.

Originally slated for release in the first quarter, the DFS delivery has been postponed owing to continued engineering work and social and environmental engagement efforts. These efforts have unearthed potential improvements to the lithium processing component of the study.

European Metals said it would make an announcement before the end of April, detailing some of the significant issues.

The company affirmed that the process flowsheet remained consistent with the October 2022 announcement, and pilot testing results from November 2023.

European Metals also stressed the extension of the study period would not impact the overall project timeline, with permitting efforts aligning with the European Union's (EU's) Critical Raw Materials Act (CRMA).

The CRMA has been formally adopted and will shortly enter into force. The act will legislate for shorter and simplified permitting processes for European critical raw materials extraction projects.

In addition, the CRMA will provide the framework for the designation by the European Commission and member States of projects deemed "strategic projects". Such designated projects will receive political and financial support to enable the projects to reach production in the shortest timeframes possible, contributing to the fulfilment of the green transition and affording the EU a degree of critical raw materials independence.

As Europe's largest hard-rock lithium mining and processing project, the Cinovec project is applying for and is expected to receive strategic project designation under the CRMA.

The project has already been granted strategic process status under the EU's Just Transition Fund.

Caterpillar Safety Services launches new programs to help build resilient safety cultures within organizations

- **Programs serve to improve the four components of a resilient safety culture.**
- **Updated Safety Perception Survey incorporates new concepts of psychological safety in safety culture management.**
- **Human and organizational performance ushers in a new understanding of human behaviour**

In its 50th year of operation, Caterpillar Safety Services incorporates the latest research and approaches to address safety excellence within organizations. With safety no longer being a box-ticking exercise but a true measure of employee engagement, Caterpillar Safety Services helps build a strong culture where safety practices are embedded across an organization.

Today, Caterpillar Safety Services assists companies with improving the four components of a resilient safety culture, where safety is approached proactively, and all team members take ownership of safety. The components include:

1. System – clearly defined safety expectations embedded in policies and procedures to identify and mitigate risk.
2. Mindset – a shared mindset that safety is everyone's responsibility, people make mistakes and an environment of openness that makes people feel safe to speak up.
3. Leadership – specific, consistent leadership behaviours at all levels of the organization that positively influence people toward safe work.
4. Ownership – occurs when all levels fully engage in the creation and continuous improvement of the safety system.

Caterpillar Safety Services recently launched two updates to its programs contributing to resilient safety cultures: an updated Safety Perception Survey and a program focused on human and organizational performance.

SAFETY PERCEPTION SURVEY

The Caterpillar Safety Services Safety Perception Survey analyses an organization's safety culture. Building on 35 years of research and study, the new Safety Perception Survey updates language and modern concepts of safety culture excellence, adding questions related to psychological safety and human and organizational performance.

The new survey's reports are streamlined with more modern visualization of the data. They measure five safety activities – hazard identification, event learning, inspections, near miss and safety meetings – and address eleven cultural indicators, including caring climate, employee involvement, feedback, management credibility, training effectiveness and risk reduction. Importantly, they also show how safety is perceived differently among employees, supervisors, and managers.

HUMAN AND ORGANIZATIONAL PERFORMANCE

Human and organizational performance is a framework

concept for talking about safety and creating a resilient safety culture. It is a mindset that allows organizations to build more error-tolerant systems by teaching leaders that expecting perfection from workers, processes, or procedures is not realistic.

Traditional methods of managing safety systems center around designing policies, standard work, and processes assuming work happens in a straight line. Management sets the expectations, tells workers what to do and the workers do it the same way, every day.

This method, however, does not account for organizational factors that can disrupt the system, such as employees not having the right tools for the job and adapting or making trade-offs because they are still required to meet production targets. Nor does it account for the individual factors that impact a worker's awareness, or lapses in attention due to events in his or her personal life, such as a family emergency. When workers deviate from the safety plan or make mistakes under the traditional model, they may be scrutinized or punished to attempt to improve safety, but this can have the opposite effect and lead to a weaker safety culture.

Using human and organizational performance principles, Caterpillar Safety Services applies a new understanding of human behaviour to safety. Leaders create an environment where employees feel empowered to speak up to share their ideas, struggles and mistakes. The organization learns to improve its safety system continuously. Through recognition of workers' positive contributions, they want to be more involved, resulting in a more engaged and proactive safety culture with improvements in morale, retention, efficiency, and profitability.

Caterpillar Safety Services assists organizations with implementation of human and organizational performance

principles through its Leadership Development and Coaching program. Tailored to the specific needs and objectives of the individual leaders, the program includes a mix of workshops, assessments, and individual face-to-face sessions. It helps each leader understand their strengths and areas for development in safety management, demonstrates how a leader impacts the safety culture, and creates personalized development plans for all leaders that align with organizational goals and processes.

‘Problem solver’ conveyor belts

Conveyor belts are critical components within many industries. They are surprisingly complex and their reliability and efficiency can critically affect productivity. Problems such as rip, tear and impact damage and repeated splice joint failures are costly to deal with and can have serious consequences in terms of lost production. Here, conveyor belt specialist Bob Nelson explains why specially engineered belts are different and recommends solutions to two of the toughest problems in conveying.

RIP, TEAR AND IMPACT

On some applications, the ability of belts to withstand the forces that cause rip, tear and impact damage is often more important than any other physical attribute. A ‘rip’ is best described as what happens when a sharp object punctures the belt and cuts the belt lengthwise as the belt is pulled against the trapped object. In contrast, a ‘tear’ is what happens when a section of belt is pulled apart in opposing directions. This tearing also includes the spreading of small areas of damage or punctures into something much more serious. Impact damage, however, is caused by heavy objects falling from height that can pierce the outer cover and damage the inner carcass.

What is most certainly NOT the answer to rip, tearing and impact damage is increasing the cover thicknesses and/or the tensile strength. Belts that are too thick for the design of the conveyor can cause different problems such as excessive rigidity (lack of troughability), steering and handling difficulties plus the very real possibility of dynamic stress failure of the belt carcass as well as recurring splice joint problems.

NOT WORTH THE SACRIFICE

When faced with repeated damage problems, one course of action is to opt for low grade, ‘sacrificial’ belts most typically imported from Asia. The sentiment seems to be that it is not worth paying good money for a belt that probably sooner rather than later will become damaged beyond repair. For me, this attitude does not make sense either economically or environmentally because it results in a lot of avoidable waste, unplanned stoppages and costs.

The materials represent up to 70% of the cost of making a conveyor belt and the only way to achieve ultra-low prices is to use low quality, unregulated raw materials. As a consequence, low-grade belts lack the necessary durability and are very easily damaged. When you add the cost of incessant patch repairs, the splice repairs, the cost of replacement belt after

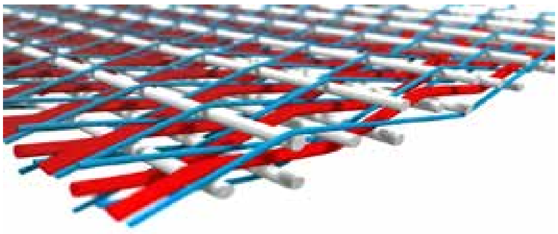
Longitudinal rips can be very expensive in every respect.

replacement belt together with the invisible 'un-invoiced' cost of the lost production while all those unplanned stoppages are taking place, the true cost is several times higher than the price paid for the original belt. As the old saying goes, price is what you pay but cost is what you spend. The fact is that for conveyor systems where ripping and tearing is a problem, the most practical and economical solution is to fit a conveyor belt that has a carcass and rubber that have been specifically engineered for the purpose.

ENGINEERED FOR THE TASK

Whenever rip, tear and/or impact damage is a concern, I recommend the use of single or dual-ply Fenner Dunlop UsFlex, even for the heaviest, most demanding applications. Although conventional wisdom would seem to dictate that a thick carcass with a higher number of inner plies will result in a stronger belt, this is not the case. The greatest influence on the strength of a conveyor belt is the actual design and physical properties of the ply material used to create the carcass.

'Sacrificial' belts sacrifice productivity, money and time.



UsFlex belts have uniquely designed super-strong fabric plies that allow the strands to gather to create amazing rip resistance.

The big advantage of the unique UsFlex carcass construction is that it has three or more times the resistance to ripping, tearing and impact compared to steel reinforced and other conventional heavy-duty belt constructions of a similar tensile strength. Protected by premium grade rubber covers, UsFlex is proven to provide up to four or five times longer operational life, especially when compared to belts imported from Southeast Asia. Although their buying price may be appreciably higher, their cost over their working lifetime is substantially less.

HOW DOES IT WORK?

What makes the UsFlex belt different is the unique, super-strong fabric ply that is manufactured in their own fabric weaving center in the USA. As the belt is being pulled through a trapped object, the design pattern of the strands allows them to gather together into a bundle that can eventually become strong enough to stop the belt or expel the trapped object. Strange as it may seem, synthetic plies are usually more effective than steel when it comes to actually minimising the length of a rip. In fact, the UsFlex fabric is so strong that it is used as a breaker ply in their steel cord belts.

THE ULTIMATE SOLUTION

It is not difficult to understand why specialist belts last so long when you hear about amazing tales of their strength like one that recently occurred in Scotland where several large pieces of granite became jammed against the tail pulley (see photo). The force was so strong that it dislocated the complete steel construction on which the tail and tensioning pulley was mounted. Amazingly, the UsFlex 1000/2 belt did not break. Instead, it simply kept on running, which just goes to show how fantastically strong these specialist belts really are and why they are considered to be the ultimate problem solver.

As with most successful products, there are several imitators who claim to have equally outstanding rip and tear resistance. However, the warning sign is that they are priced considerably lower. How this is achieved is probably best explained by the fact that, as laboratory testing consistently confirms, their rip and tear resistance is more than 60% lower than the real thing.

RECURRING SPLICE JOINT FAILURES

An even more common problem than rip and impact damage

Trapped granite buckled the conveyor, but the UsFlex belt kept on rolling

is splice joint failure. The weakest point of any conveyor belt is the splice joint. In fact, it is estimated that nearly 80 percent of all conveyor stoppages are caused by splice joint problems. Because of the potential loss of output, as well as the safety implications, it is critically important to maximize the strength and long-term durability of the joint.

The most common method of making a splice joint is the step splice, which requires the removal of one of the layers of fabric plies so that the two belt ends can be overlapped and then either cold glued or hot vulcanized together. This method is popular because it is seen to be generally easier and quicker to make a step splice. However, these ‘advantages’ come at the expense of the far superior strength and reliability achieved by using the finger splice jointing method. For those who may not be familiar with the term, finger splicing is where a zigzag pattern is cut into both sides of the belt ends, creating several interlocking ‘fingers’. These are then carefully aligned, interlocked together and finally bonded using a hot vulcanizing press to make a splice that is very strong and flat.

Regardless of the method used, it is not physically possible to join a belt without some loss of longitudinal tensile strength, However , the big disadvantage of the standard step splice is that it will always create a proportional loss of tensile strength equivalent to one ply.

As can be seen in **Table 1**, a 3-ply step joint can only achieve a maximum longitudinal tensile strength of 67%. This effectively means that in a typical multi-ply belt containing three plies or more, at least one ply exists purely to compensate for loss of the longitudinal strength incurred by making a step splice joint. In contrast, the finger splice method retains up to 90% of the belt’s ‘static’ tensile strength. Another advantage is that the finger splice is much more resistant to dynamic stress failure. Very importantly, this superior strength and durability also reduces the need to repair and re-splice, thereby significantly reducing both direct (actual repair) and indirect (lost output) costs.

Table 1

No. of plies	Maximum % tensile strength
1	90%
2	50%
3	67%
4	75%
5	80%

In my view, the biggest opportunity of all is the very real chance to install a much more reliable and consequently lower ‘whole-life’ cost ‘problem solver’ belt in the form of Fenner Dunlop’s revolutionary single-ply Ultra X belt. As with UsFlex, the secret behind the Ultra X phenomenon is its ‘in-house’ unique super-strength fabric that possesses more than 3 times greater longitudinal rip resistance, up to 5 times better tear resistance and a far better resistance to impact compared to traditional 3-ply or even 4-ply belting.

Finger splice joints are much stronger and reliable.

Ironically, the finger splice is an integral factor in the success of Ultra X because of the vastly superior splice joint strength and reliability. For example, one quarry in the UK had been replacing splices on its multi-ply belts every three months. However, more than 18 months after installing Ultra X single-ply belts, it had not been necessary to repair or replace a single splice.

NEW WAYS TO SOLVE OLD PROBLEMS.

For some, the very idea that a conveyor belt with only one or two plies can be dramatically stronger than a belt with multiple plies may not make much sense but the answer lies with manufacturers who are prepared to innovate using modern technology to find new ways to solve old problems. As a result, problem solver belts like UsFlex and Ultra X consistently prove themselves to be the cheapest to run because that is exactly what they are designed to do, which is to run and run and run. Problem solved.

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