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A Study of Processing Options of Mineral Concentrates: Onshore vs Offshore considerations

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Abstract

Over the years, most of the mineral resources with higher value have already been developed. Therefore, mineral resources with lower value and a higher level of impurities will need to be developed to cater to the increasing global resource demand. In an Australian context, mineral processing dependency on offshore facilities has been dominant compared to the onshore processing facilities, particularly to reduce the higher development costs. In addition, impending restrictions on the constituents such as penalty elements during transportation of mineral concentrates will lead to restrict the offshore processing flexibility. Innovation of low cost development methods to produce high value mineral concentrates will be vital. Amount of impurities could substantially impede the marketability of any mineral concentrate. Therefore, upgrading of mineral concentrates in onshore facilities will become vital for the Australian developers to eliminate penalty elements associated with high value concentrates.

This study will review the economic context of Australian copper resources with penalty elements. More prominence is given to the processing facilities with the potential to remove a host of impurity elements at a lower energy dependency. Overall, this study contributes to the understanding of mineral resources and the emerging challenges for better decision making and planning in the mining processing industry.

Keywords: *mineral resources, impurities, processing*

1. INTRODUCTION

More than 90% of world copper production is produced pyrometallurgically from sulphide copper ore (Ayres et al., 2002; Davenport et al., 2002). Among the copper sulphide ore, the primary mineral is chalcopyrite ($CuFeS_2$) contributing to 50% of total copper production and the rest is sourced from bornite, chalcocite, covellite and others (CDAA, 2017). However, as the high-grade copper deposits in the world becoming depleted, there is an increasing focus on developing lower-grade ores which contain challenging impurities such as arsenic, lead and cadmium (CSIRO, 2015). Lead is a toxic heavy metal whose use and emission has been restricted in recent years. It is a neurotoxin and can cause anaemia at levels of 80–100 µg/dL in blood (Goyer and Clarkson, 2001). Higher levels can be fatal. In addition, other impurities such as arsenic, antimony, bismuth, selenium, tellurium, nickel and cobalt also needs to be removed in final concentres to avoid smelter penalties (Fountain, 2013). As an example, presence of arsenic is problematic as these minerals are generally concentrated with the sulphide copper minerals during flotation leading to high impurity copper concentrates, destined for smelting. The current general industry practice is that copper smelters only accept concentrates with less than 0.2% (i.e. 2000 ppm) arsenic without payment of any penalty by the seller of the concentrate (Bruckard et al., 2010). If the arsenic content is between 0.2 to 0.5%, some penalty is imposed on the price received for the concentrate. Concentrates with more than 0.5% arsenic content are not generally accepted by the smelters. Large scale low grade deposits require more energy intensive extractive techniques, endure higher waste to ore strip ratios, abundant with problematic deleterious elemental impurities, occurring as gangue minerals or inclusions, or are intimately intergrown within the economic minerals (Mudd, 2007; Northey et al., 2014).

2. COPPER MARKET CONTEXT

Metal commodity prices are very sensitive and controlled by the market developments, leading to cyclitic trends. The world copper prices have crashed in 2008 as illustrated in the Figure 1. However, copper price doesn't show a direct correlation with the copper consumption. Copper price draw down may be due to the increased recycled copper production associated with lower development costs. The world copper consumption has shown a positive correlation with the world GDP (Figure 2).

However, historically the global demand for copper has grown by approximately three percent per annum having been instigated due to growing needs (Barr et al., 2005). Simultaneously, mining companies are constrained by the operating cash flow, mineral production costs are rising due to the low value of current ores associated with fluctuations in metal price. The cost of production also requires substantial capital investment in addition to the continual operation expenditure (Boulamanti and Moya, 2016; Hollitt, 2012; Runge, 2012). The continued expansion within the mining industry to meet the copper demand can be observed in the transition towards complex lower grade ore deposits associating a host of impurities, which can negatively affect the operating cash flow by decreasing the gross value of the metal commodity or require research and development into impurity removal technology (Barr et al., 2005; Northgate, 2001).

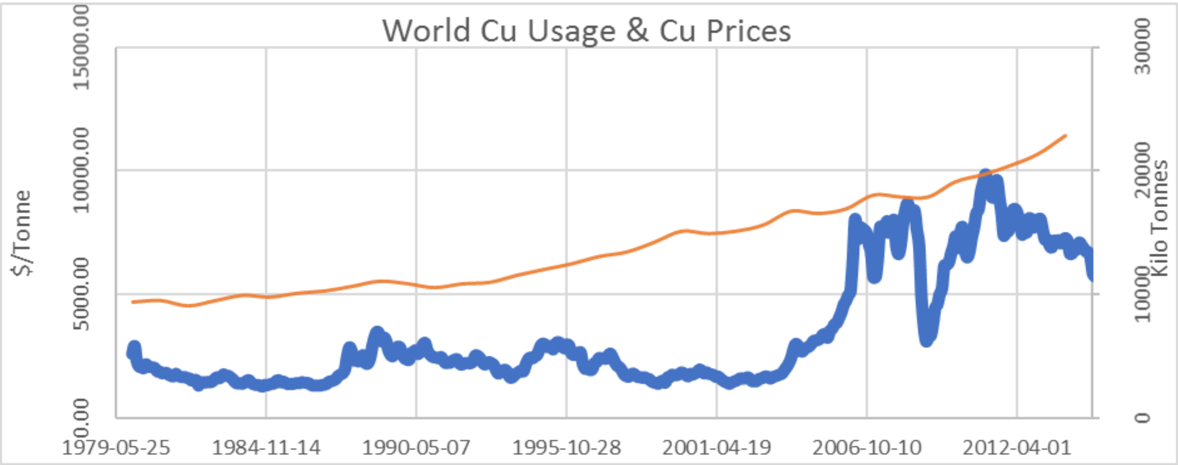

Figure 1. World Copper usage and copper prices 1979 – 2015

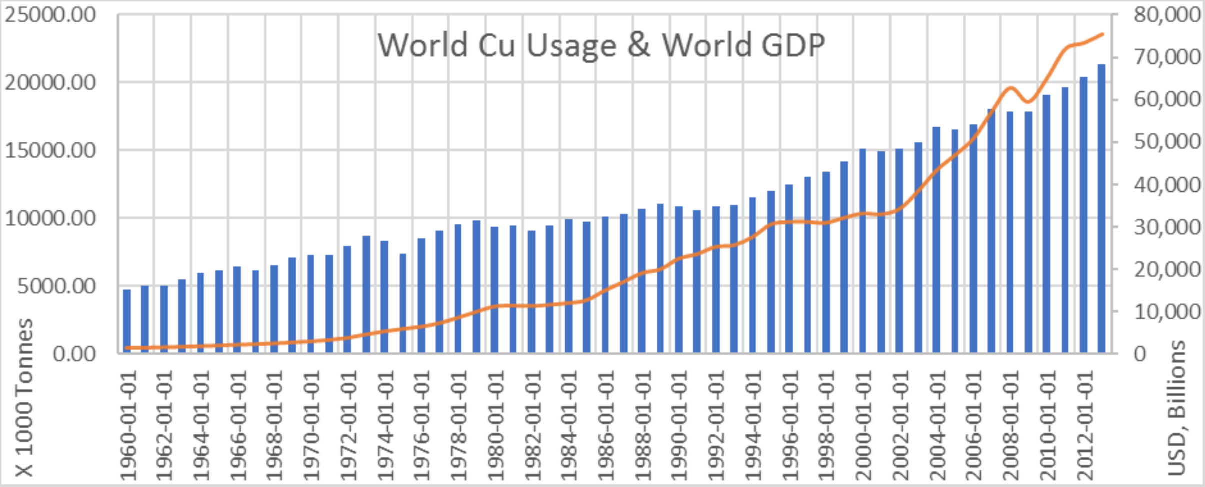

Figure 2. World copper usage and world gross domestic product from 1960 – 2013

3. COPPER PROCESSING ECONOMICS

The cost of copper production requires substantial capital investment for mining projects to invest in processing facilities. Ullmans (2001), states that mining projects are financed by large consortiums and banks to support the large capital investment. Capital investment into green-fields smelters in 2001 were estimated between USD 2500-3000/t of the designed copper production. Operationally the process of extraction through mining and milling and, enrichment through smelting and electro-refining is a very energy intensive process. Ullmans (2001) copper economics study suggests that for produce one tonne of copper through the primary pyrometallurgy copper production process consumes 45 GJ per tonne or 12,500 kWh. The energy consumption was split evenly between mining and smelting. In regards to secondary copper recovery, recovered from copper scrap or refining wastes the energy consumption is significantly reduced to 20GJ/t copper, or 5,555 kWh. Barr et al (2005) study on the CEL SX/EW production plant suggest that power consumption and electricity costs account for 45 percent of the operating cost of the refinery. There might be a slight discrepancy between energy consumption from site to site, but smelters are generally more capital intensive. However, smelting is more energy efficient than hydrometallurgy based on an operational cost of USD 66/t.

Barr et al (2005), suggests that treatment and refining charges averaged at 23 percent of the copper price. Copper smelters base treatment charge on average is around USD 5.00/t charge up to gross value USD 20.00/t. Therefore, the profit margin of the smelter refineries is marginal. For both to perform optimally and maximise the process copper concentrate needs to be consistent. According to Ullmans (2001), in 2001 80 percent of copper production was from low grade Cu ore, or poor sulphides ores. This trend has continued as mining projects are investing into lower grade deposits as extraction technology has increased making them more economical. As Cu percentage decreases, it could associate a higher level of penalty elements in final concentrates (Cowan et al., 2012). Oxide ores such as; cuprite, azurite and malachite contain the following impurities; sulphur, iron and antimony attached to precious metals. Sulphide ores contain sulphur, arsenic and antimony, which are reduced during a preliminary roast. In congruence with declining copper price and the increased level of impurity elements, smelters refineries developed impurity penalties to the producers of copper condensate (911metallurgist, 2017; Appi, 2016), observe impurity penalties in Table 1. The treatment penalties are enforced if the concentrates influence; the preparation of the blast furnace charge, the collector, the formation of the slag and the refined base bullion.

Table 1. Impurity penalties for copper concentrate associated with treatment and refining contracts

Elemental impurity	Penalty and conditions
Zinc	30 US cents per unit in excess of 6%
Arsenic	50 US cents per unit in excess of 1%
Antimony	1 USD per unit in excess of 1%
Moisture	10 US cents per unit in excess of 12%
Bismuth	50 US cents per pound over 0.05%

Process economics is an important economic assessment to evaluate the cost-benefit comparison of processes. The assessments can be used to characterize and evaluate the economic feasibility of a specific project, investigate cash flows (e.g. financing problems) over the lifetime, evaluate the likelihood of different technology scales and applications and compare the economic quality of different technology applications providing the same service. Net present value (NPV) or otherwise known as discounted cash flow, is one of the most practical process economics and techno-economic tools for assessment (El-Halwagi, 2017). It represents the difference between the present value of cash inflows and the present value of cash outflows. It stages the value in real terms as the money value will diminish over time per the discount rate. Net present value equation is as follows:

$$\mathrm{NPV}_{tot} = \mathrm{NPV}_n = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{1}$$

Where, Ct = net cash inflow during period t, r = discount rate, t = number of time periods

4. RESULTS

Onshore processing cost analysis has been conducted using the dataset tabulated in Table 2 (Barr et al., 2005; Haque et al., 2012; MPRA, 2013; OZMinerals, 2014). A discounted cashflow model has been developed to analyse the effect of penalty elements, capital costs, transport costs and transport costs. These cost parameters correspond to a copper processing plant to screen impurities for a duration of 20 years in Australia. Net smelter returns are calculated based on the penalty rates associated with the common impurities including Zinc penalty rates and TC/RC charges (Boulamanti and Moya, 2016; Burton et al., 2017; Haque et al., 2012; Norgate, 2001).

Table 2. Copper Economic Analysis model parameters – Onshore facility

Model Parameters	
Mine Life - Pre-production (years)	5
Mine life – Production (Years)	20
Tonnes of Resources (Mt)	80
Dilution (%)	10.00%
Mill Recovery (%)	92.00%
Tonnes of Pre-Strip (Mt)	12
Diluted Grade of Gold (g/t)	1.03
Diluted Grade of Silver (g/t)	2.5
Diluted Grade of Copper (g/t)	1.96
Strip Ratio	6.5
Diluted Resources (Mt)	88
Reserves of Ore (Mt)	80.96
Waste (Mt)	520
Total tonnes mined (Mt)	612.96
Strip Ratio after dilution and recovery including pre-strip	6.42
Strip Ratio after dilution and recovery	6.57
Capital cost	$ 975 million

Table 3. Net Smelter returns – Offshore facility

Model Parameters	
Spot Metal Price	$ 8,500.00
Concentrate Grade	60.00
Gross Value of Recovered metal / t Concentrates	$ 3,834.59
Payable Concentrate Grade	59.00
Value of Payable Metal / Tonne Concentrates	$ 3,638.70
Concentrate Ship Transport	$ 86.00
Treatment Charge / Tonne Conc.	$ 100.00
Refining Charge / oz or lb of Metal	$ 6.95
Zinc Type AUD/t PP above & $ TC change/t metal	$ 5.55
Lead Type AUD/lb PP above & $ TC change/lb metal	$ 3.30
Total TC/RC/PP Per Tonne of Concentrates	$ 201.80

5. DISCUSSION

NPV has been estimated based on the offshore processing carried out for 20 years to be $8,337.832 based on a 20-year production life span. Based, on an annual basis on shore processing costs has been estimated as $293 compared to $201.80 (Table 3) of smelter concentrate processing costs at offshore smelters when estimated on a per tonne basis. Therefore, if the processing carried out using the offshore smelter will lead to a more than 30% saving. However, increased smelter penalties and International Atomic Energy Agency (IAEA) regulations on radioactive isotopes can lead to change the offshore cost spectrum substantially. In the current context, annualised costs of processing in onshore is much higher than the offshore costs. The intended regulations by IAEA could also lead to the rejection of concentrates with a high level of radionuclides such as the Pb-210 or Po-210. Therefore, despite the economic unfavourability, it is important to maintain onshore processing centres to ensure even the concentrates with a high level of impurities can be made economic with the existing facilities. In addition, onshore processing will lead to savings on transportation costs, smelter penalties and treatment and refinery charges. Depending on the scale and richness of the resources the impending savings will vary. In offshore smelters, TC/RC rates are around USD 90 – 110 per tonne, in addition to the international transportation costs (Burton et al., 2017). However, these smelter costs are sensitive to the global market prices. Therefore, higher smelter penalties could make onsite processing more attractive in the long run for any resource with a high level of impurities. The blending or increased amount of impurities can lead to low returns. This is particularly challenging for low value resources. Therefore, in the future it is not only critical to evaluate the basin wide characteristics of any copper deposit but also the economic attractiveness will be a substantial consideration along with onsite or offsite processing option for any potential resource.

6. CONCLUSIONS

The costs associated with the processing of copper concentrates with a high level of impurities can impede the economic benefits. This study, conducted a comparison of the copper concentrates subjected to offshore and onshore processing. In the current context, onshore processing costs are 30% more expensive compared to the offshore processing costs. Therefore, it may not be economical to process copper concentrates in an onshore facility. However, concentrates with penalty elements will make it compulsory to remove such elements in the final concentrate to comply with the international transport safety standards. Therefore, in the process such needs and other benefits of savings from transportation and smelter penalties could make onshore processing attractive in the long term.

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