ICSG Insight

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HAZARDOUS IMPURITIES IN COPPER RAW MATERIALS: NEW DATA, REGULATION AND INDUSTRY RESPONSES

Summary

This insight is mainly focused on arsenic in copper concentrates, but other minerals such as mercury are included. The work summarizes information from many technical sources on the subject of minerals accompanying copper ore and copper concentrates, discussed in the International Seminar on Impurities on Copper Raw material, organized by JOGMEC in Tokyo, Japan in October 2018. It also includes ICSG Secretariat research and information contained in technical papers published at recent metallurgical conferences. The paper starts by describing the current situation of the global copper concentrate market, the drivers of its current performance and the trends for hazardous residuals in copper smelter products. A brief discussion on copper mine tailings and other mineral waste regulation is followed by the analysis of arsenic content in copper concentrates and the flows of arsenic to treatment plants and roasters. A discussion on current and future high arsenic copper mines to estimate the expected arsenic content in future copper concentrates is followed by estimates of arsenic content in clean and in complex global copper concentrate output.

Recent Japanese and Chinese copper smelters data is presented to measure how arsenic content is growing in blended copper concentrates from copper mines exporting concentrates to Japanese smelters reporting. After introducing different estimates regarding the flow of arsenic being processed by Chinese copper smelters, selected new regulatory developments affecting copper concentrates impurities, recycled copper from scrap and copper smelters operations are discussed. An assessment of the current situation of copper concentrate blending plants is followed by a discussion of the risks faced by copper smelters to lose their social license given the situation of the impurities in concentrates.

A review of the response of Chinese copper smelters to blend and also to develop innovative processes to treat the increasing volume of residuals is presented and followed by a summary of the risks in the EU and elsewhere to trade and process high mercury copper concentrates as the Minamata Convention is implemented worldwide. Challenges to the modernization of copper smelters with state of the art pyro and hydro-metallurgy solutions, are compared to technologies looking to reduce the inflow of impurities in the concentrate before smelting and before shipping the concentrates from mining areas. Technologies under development to remove arsenic directly from copper ores are introduced, and the emerging use of some hazardous residuals in new materials. The Insight concludes with a short discussion of options for inter-governmental efforts to continue monitoring and to reduce the dispersion of the increasing flow of hazardous waste associated to copper ores and copper industry processing plants.

Impurities in Copper Concentrates and Their Impact on Copper Smelters. The global copper concentrates market used to be bipolar in the past, with two different markets operating at the same time. One market used to be for Japanese, European and other copper smelters using clean copper concentrates, and other market existed for complex copper concentrates containing undesirable impurities as As, Sb, Bi, Pb, Zn F, Cl and Hg. The demand for complex copper concentrates in the past, included smelters specialized in processing complex concentrates. These smelters included a Japanese smelter that now is focused in electronic scrap (Kosaka), and others such as the Ronskar smelter in Sweden (now processing more scrap), the Tsumeb smelter in Namibia, the Hoboken copper-lead smelter in Belgium, the Horne copper Smelter (Quebec) in Canada , Chile Alto Norte smelter and Perú closed La Oroya smelter. As an outcome of closures and technology changes in most of the complex smelters, with the emergence and market domination of the Chinese smelters in the last two decades, and with the dilution of complex concentrates in blending plants, the differentiation between the clean and the complex market is now vanishing. So complex copper concentrates are not flowing to specific copper smelters as in the past, therefore more arsenic and other impurity burdens are being placed on the custom copper concentrate market now. Not only increasing arsenic content in copper concentrates, but also driving a change in the industry structure.

Expansion of the Chinese Copper Smelting Capacity. China is increasingly dependent on imported raw materials as it hosts only 6% of the copper mine capacity, 30% of the world smelting capacity and 46% of the global fabrication capacity with more copper smelter and copper refinery capacity in the 2018-2021 project pipeline. China copper smelter capacity is increasing from 3.8 Mt in 2010 to ~9.9 Mt in 2021 so more demand for clean copper concentrates and clean scrap is expected. China smelting capacity already increased 700 kt over the first seven months of 2018 and might add +2.0 Mt by 2021. As most of the new and future smelting and refinery capacity will be located in Asia, a more complex concentrates supply will primarily affect this region.

More Impurities in Copper Smelter Products Worldwide. Between 2003 and 2016 the arsenic content in global copper anodes output increased by over 80%, the lead and mercury contents increased both almost 40%, the bismuth content increased over 20%, the nickel content in copper anodes almost 20% and the content of selenium by more than 5%. Global flash smelter technology capacity increased over 300% over 1995-2015. In many cases flash and other smelters re-circulate arsenic rich solid waste to recover copper, increasing the risk of arsenic emissions.

Impurities in Copper Industry Mineral Waste and Scrap. Tailings and other mineral waste are in the regulatory spotlight as copper concentrates production broke global records in recent years and is recovering fast in 2018 from a temporary shortage in 2017. Copper mine tailing storage facilities risks are expected to be reduced by new regulatory approaches after failures in Canada, Brazil, Australia and other countries: legacy waste and water management are key but expensive issues regarding new mine closure regulations. Europe, North America and other exporters of recycled copper waste and scrap face a domestic glut of scrap and recycled waste following the implementation of China's solid waste import ban in 2018. Japanese smelters had been increasing the use of scrap but at a limited speed and volume, so with limited inputs of recycled copper flowing to smelters the changes in the composition of copper concentrates supply will remain a core challenge for the copper smelting industry in 2019 and beyond.

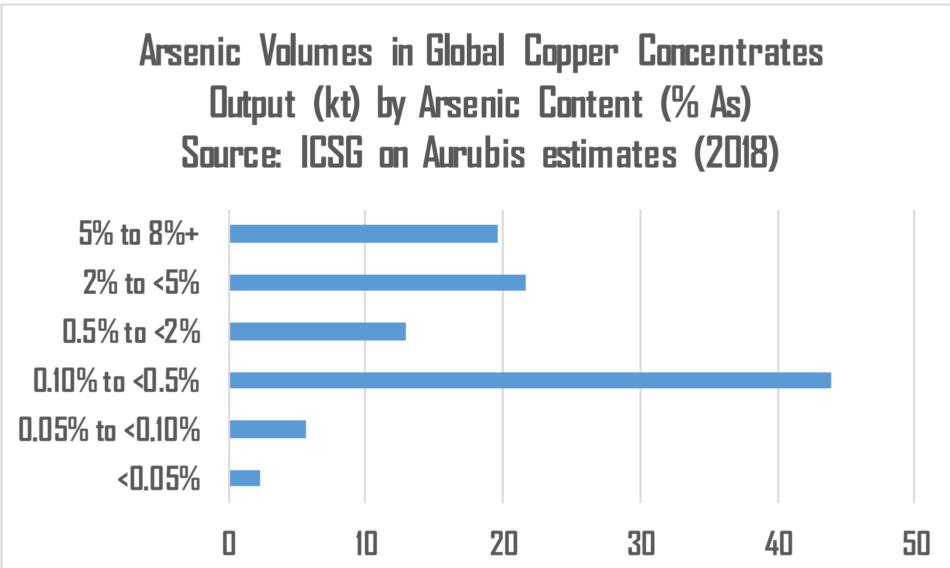
Global Arsenic Balance Estimates. Metal Economics Research Institute, Japan (MERI/J) had developed their own global balance of arsenic in copper concentrates processed worldwide, estimating that the annual growth of arsenic processed is increasing, to achive a total volume close to 150 thousand tonnes per year. This approach estimates that around 51% of the arsenic goes to integrated mines and smelter complexes, meanwhile 33% goes to custom smelters and only 16% to roasting plants specialized in remove arsenic from copper concentrates. According to MERI/J close to 50 kt of arsenic per year flows to custom smelters, with around 40 kt going to Chinese custom smelters and only 10 kt to custom smelters out of China. The remaining 100 kt of arsenic is split between 76 kt processed by integrated copper mine and smelter complexes, meanwhile the balance 24 kt goes to roasting plants where the arsenic is extracted and the outcome is "clean" copper concentrate.

Arsenic Content in Copper Concentrates. According to recent data presented by Aurubis in October 2018, the estimated arsenic content in the supply of copper concentrates was at least 106 thousand tonnes globally in 2016, and is expected to grow in the future. The difference with MERI/J estimates of arsenic balances is explained because upstream arsenic extraction is not included. On average the arsenic content in global copper concentrates production was stable at around 0.17% arsenic in 2004-2013, increasing from 0.13% arsenic in the year 2000 according to recent research from Japan Metal Research Institute (Metal Economics Research Institute, Japan). However, in the period 2014-2017 they observed an accelerated growth from 0.18% to 0.22% arsenic in the mentioned years. According to ICSG estimates the global average arsenic content in copper concentrates might have achieved 0.25% in 2016 and are expected to be higher in 2018. So the current average arsenic content is around 50% of the maximum limit accepted for arsenic content in imported copper concentrates in China. In 2017 Chinese smelters treated around 30 Mt of concentrates to produce less than 6.0 Mt of blister and anodes from concentrate.

Main Arsenic Sources and Forecast of Arsenic in Copper Concentrates. According to Aurubis estimates reported in October 2018, the content of arsenic in the exports of copper concentrates from Chile and Peru accounts for most of the global arsenic content of copper concentrate production, with at least 70 kt per year for both countries in total. According to data presented by MERI/J, an important source of the increase of arsenic content in Japanese imports of copper concentrates in recent years is the high arsenic content in some concentrates from mines in Chile such as Escondida, Collahuasi and Los Pelambres but also from the Northpakes copper mine in Australia. Other sources of increasing arsenic mentioned by MERI/J are the Chuquicamata, Toromocho, El Brocal and Chelopech mines among others. According to different studies the global average arsenic content in copper concentrates increased from around 500 ppm in 2010 to around 1700 ppm in 2015, jumping from around 1000 ppm after the start-up of the Ministro Hales and Toromocho mines in South America. According to MERI/J, over the period 2018-2020 it is expected that the arsenic content in copper concentrates will increase worldwide to around 0.22%. Then in 2030, with the start-up of high arsenic content mines such as Tampakan, Marcapunta Oeste, El Galeno, La Granja, Wafi-Golpu, Canariaco Norte and others it could increase to over 0.3% arsenic.

Arsenic Content in "Clean" Global Copper Concentrate Output. The definition of complexity of a copper concentrate is a practical expression related to the limits of arsenic content below 0.5%, necessary to access the Chinese market. As arsenic content in copper concentrates has gradually increased, the ability to blend these complex concentrates with clean concentrates is being compromised. As the global production of copper concentrates is expected to approach 70 million tonnes worldwide in the next 2 or 3 years, the content of arsenic in "clean" copper concentrates (those with arsenic content below 0.5%) is now around 51.8 thousand tonnes or 49% of all the arsenic content in copper concentrates. But if we look at the arsenic content inside the "clean" concentrates group, most of the arsenic in copper concentrates output is now in the higher range of arsenic content between 0.1% and less than 0.5% arsenic. So any restriction below the current <0.5% limit set by China could reduce the volume of copper concentrates that now are accepted to be imported to China.

Arsenic Content in "Clean" Copper Concentrates. The arsenic content in "very clean" copper concentrates, with less than 0.05% of arsenic is only 2.2% of all the arsenic traveling in the copper concentrate production every year. Meanwhile the arsenic content in "not very clean" copper concentrate, with arsenic in the range 0.05% to <0.10%, is only slightly above 5 thousand tonnes a year. So most of the arsenic content in copper concentrates defined as "clean" is now in the range 0.10% to <0.5% arsenic: this 43.9 thousand tonnes of arsenic in this higher range of clean concentrates, equivalent to 41.4% of the all arsenic content in global copper concentrates, or 85% of all arsenic content in "clean" copper concentrates. In consequence, almost half of the arsenic produced every year in copper concentrates is being spread around the world every year in arsenic contents tolerated by most of the copper smelters including Japan, Europe and China, even when Japan and Europe have more strict limits on arsenic in copper concentrates versus China, a fact that might change in the future.



Arsenic Content in "Complex" Global Copper Concentrate Output. Arsenic content in the global production of "complex" copper concentrates (0.5% arsenic content or more) was around 54.2 thousand tonnes of arsenic per year in the data estimates published most recently (October 2018). This volume represents over 51% of all the arsenic contained in copper concentrates every year. In the case of "complex" copper concentrates the volumes of arsenic contained in the copper concentrates extracted every year from copper mines are increasing with the arsenic content. So "complex" copper concentrates with 0.5% to less than 2% arsenic content contains 12.9 thousand tonnes of arsenic or 12.2% of the global arsenic in copper concentrates produced every year, meanwhile "more complex" copper concentrates with 2% to <5% arsenic content, contain around 21.7 thousand tonnes of arsenic equivalent to 20.5 % of the arsenic content of copper concentrates annual production. "Very complex" copper concentrates with 5% to 8% or more arsenic content are holding around 19.6 thousand tonnes of arsenic, equivalent to 18.5 % of the global arsenic in copper concentrates extracted every year using the 2017 data published recently.

Arsenic in "Clean" Copper Concentrates Processed by Copper Smelters in Japan: Arsenic content trends processed in Japanese copper smelters is closely tracked, so this is a valuable data source to understand what is happening with the arsenic content in copper mines exporting concentrates to Japan and other markets. On average, the content of arsenic in copper concentrates imported to Japan used to be stable around 0.05% arsenic in the period 1991-2001. By 2017 the arsenic in copper concentrates treated by Japanese smelters had increased to close to 0.1%. Meanwhile the copper content that used to be around 30% in 1991-2001 has been falling, with current levels around 26% copper in the imported concentrates reported by Japanese smelters.

Arsenic in Copper Mines Exports of Copper Concentrates to Japanese Smelters. Arsenic content in copper concentrates imported to Japan from the Escondida copper mine in Chile was close to 0.04% in 2002 according to MERI/J recent reports and in 2016 it had increased to as much as 0.20%. Meanwhile in the case of copper concentrates imported by Japanese smelters from the Collahuasi copper mine in Chile, the arsenic content has been increasing very fast, from less than 0.1% arsenic in 2011 to over 0.25% now. In the case of copper concentrates imported by Japanese smelters from the Los Pelambres copper mine in Chile, arsenic content was almost zero in 2008 and in 2013 achieved over 0.25% arsenic. In Australia, the Northparkes copper mine, copper concentrate arsenic contents imported by Japanese smelters has been growing exponentially, from 0.05% in 2007 to over 0.35% in 2013. (MERI/J, October 2018). Some are proposing that copper miners should remove and stabilize impurities, but it is not proper answer according to MERI/J. It is depending upon cost sharing among related interested players in the value chain such as mining companies, smelting companies and governments. Roasting technology has been established and arsenic can be removed easily if trade restrictions increase. How the arsenic removed is stabilised in a non-hazardous residual is a central subject. According to MERI/J, at Ministro Hales mines in Chile, the final arsenic compounds are calcium arsenite that is not stable so crystalline scorodite should be formed to get long term stability for storage. A necessary step ahead is to how much cost will be required and which place is better and so on. Such a cost should be distributed across the value chain after such a discussion according to MERI/J views.

How Far Can the Chinese Smelters Absorb Arsenic? Research published in EMC 2017 by Beijing General Research Institute of Mining and Metallurgy (BGRIMM) estimated that Chinese copper smelters processed around 50 kt per year of arsenic before 2017 and ICSG estimates that arsenic inflows to Chinese copper smelters were close to 67 kt in China for 2017. Average copper concentrates treated in Chinese smelters contain 18% to 20% copper and 0.20% to 0.25% arsenic. Over 10 kt of arsenic outflows are coming as flue dust, black copper from matte, arsenic sulfide and other soluble residuals. If we look only at Chinese imports of arsenic in copper concentrates, Japan's MERI/J estimates that China has been importing around 43 kt of arsenic per year, at an average content of 0.25% in 17.3 million tonnes of copper concentrates (gross weight) imported in 2017. MERI/J estimates that the arsenic treatment capacity of Chinese smelters is close to 95.2 kt-As and can treat up to 62.2 kt-As entering China every year in imported copper concentrates and a capacity to treat up to 33 kt of arsenic coming from domestic sources. This treatment capacity is based on 23.4 million tonnes of copper concentrates treatment capacity (domestic plus imported), 6.2 million tons of gross weight copper content in domestic concentrate (1.6 Mt-Cu) and imported concentrate (4.5 Mt-Cu) per year.

Arsenic Flows in China Copper Industry: MERI/J Estimates. Assuming a spare capacity of 22 kt per year, MERI/J estimates that the arsenic treated in China copper industry is close to 73 kt per year, very close to ICSG secretariat estimates, with around 40 kt of arsenic in copper concentrate imports and 33 kt of arsenic coming from domestic copper concentrate sources. This corresponds to 16 million tonnes of copper concentrates supply with an arsenic content of 0.14% on average, assuming a 28% copper content. MERI/J's conclusion is that the main challenge for the short term is to understand how arsenic residuals from copper smelters have been disposed of across China in recent years and the plans for future arsenic stabilization and disposal. According to MERI/J experts, China has been treating high volumes of arsenic so far and will treat more than 100kt/y in the future. However, they reported that most of arsenic contained residues are treated by third parties who hold special licenses to treat hazardous waste in China so, according to MERI/J, those copper smelters are not involved in arsenic stabilization and disposal in China after paying for external treatment charges. So their conclusion is that nobody knows what is the real arsenic treatment situation in China now. MERI/J also reports that China is the biggest country to produce phosphate ore to produce phosphoric acid and a lot of arsenic is contained there. So China has at least two big sources of arsenic, one is copper concentrates and the other is phosphate ore. According to their estimate, China actually might be producing more than 200kt per year of arsenic combined from both sources.

Arsenic Flows in China: Chinese Academy of Sciences Flow Model. A recent study from the Chinese Academy of Sciences published in 2017 by the American Chemical Society (Anthropogenic Cycles of Arsenic in Mainland China: 1990−2010) reports that China has become the biggest miner of arsenic-containing ores, and remained the biggest producer of arsenic trioxide, the source of almost all arsenic uses, since the mid-1990s. Mainly mined as a companion material of copper, lead, tin, and zinc, the demand for arsenic in China and elsewhere is much less than the amount of arsenic co-mined with nonferrous metal ores, dealing now with arsenic-containing by products, tailings, slag, flue dust, and wastewater. Nonferrous metal ores with high arsenic concentration and mineral residuals are found in only a small number of provinces including Guangxi, Yunnan, and Hunan, unevenly distributed in these provinces. The oversupply also leads to a low market price of arsenic in China, making it not economical to recycle arsenic at the end-of-life stage and resulting in a lack of economic incentives to develop arsenic recycling technologies. The study estimates that China's growing domestic use and exports of arsenic since the 2000s was mainly driven by the growing manufacture of batteries and semiconductors, glass making and alloys. The study suggests that Chinese policy makers pay more attention to mined ores and processing plants in controlling arsenic losses to soils, call to reduce or restrict the export of arsenic containing materials, and regulate the use as well as prevent the dissipative emissions of arsenic from some growing applications such as glass, batteries, and semiconductors. Recently, China's Ministry of Environmental Protection released a Technological Policy on Arsenic Pollution Prevention and Treatment that aims at restricting arsenic use or promoting alternative materials and technologies in agricultural applications, glass making, and wood preservatives.

New Guidelines Affecting Copper Smelters Concentrate Supply and Emissions. ICSG secretariat research in 2017 and 2018 has revealed that new regulatory developments are being discussed in 2018 to control copper concentrates impurities. More complex copper concentrates are in great part a consequence of a concentrates trade boom driven by increased copper smelter capacity in China. This fact is linked to lower copper ore grades in copper mines in recent years that are increasing costs of energy, water and hazardous waste disposal. Occupational risks related to carcinogenics, mainly arsenic and mercury, but also on sulphuric acid mist and nickel and more UN related environmental guidelines for miners (UNEP, IMO, ISA, APEC) from seabed mining, copper concentrate transport to tailings are expected to continue constraining the growth of the mine supply side of the copper industry. Copper concentrate impurity import restrictions have been operating in countries such as Japan and China for many years. In 2018, China increased regulatory pressures on copper processing plants emission controls, environmental taxes and also implemented "polluter pays" principles. Stricter sulphur and particulate materials (PM) emission rules are being implemented in Chinese copper smelters in 2018, and it is possible that As, Hg and Pb emission limits to smelters will be tightened. It is also possible that the arsenic limit in copper concentrate imports to China could be reduced to as low as 0.3% from the current 0.5%. So processing copper concentrates close to manufacturing centres might be increasingly more expensive and the reallocation of smelting processes to mining districts might be encouraged.

More Strict Air Emission Standards for Arsenic in Chile. In the case of Chile copper smelters historically processed concentrates with high volumes of impurities on average, and copper mine supply complexity is increasing in Chile, so local smelters are processing higher volumes of arsenic and other impurities. The implementation of Decree No.28 in December 2018 in Chile calls for a 35% reduction of arsenic emissions from around 700 tonnes per year to only 476 tonnes per year by 2019. If these targets are achieved, the arsenic collection efficiency would need to be close to 90%. According to COCHILCO, the expected arsenic capture in Chilean smelters must be at least 95% in 2019, with a maximum limit of 1 mg/m3 monthly average in existing and new sulphuric acid plants and the same limit for the slag cleaning furnaces. In 2018, different governments are estimating costs of copper smelter closures related to more stringent emission limits. As in the case of India, other countries are facing the prospect of temporary or even permanent closures of copper smelters if social licenses are lost.

Stricter Arsenic Emission Standards for Smelters in Japan. In Japan, there are no regulation regarding air emissions of arsenic (JOGMEC 2018) but there are "guidelines" on air pollutants according to JX Nippon Mining and Metals (2018) as strict as 6 ng/m3 for arsenic, 25 ng/m3 for nickel and 40 ng/m3 for mercury in air. With an increasing input of arsenic to the smelters operations are becoming more difficult and it is expected that much more arsenic will remain in the process if emissions are controlled and will need to be disposed of properly. In Japan, the maximum limit for waste water emissions is 0.1 mg/lt for arsenic, lead and selenium and much stricter for cadmium (0.03 ml/L), but more permissive for copper (3 mg/L), zinc (2 mg/L) and chromite (2 mg/L). According to JOGMEC a stricter limit exists for arsenic in surface water concentrations (0.01 mg/L) and for underground water (0.01 mg/L), meanwhile copper smelter slag should not have a content over 150 mg/kg of arsenic and 0.01 mg/L of arsenic in solution.

Environmental Deregulation in Copper Mining Countries. In copper mining countries a new trend to reduce green tape regulations might allow protected sectors of the economy to continue delaying smelter modernizations resulting in smelter closures as a new generation of cleaner and more competitive copper smelters emerges in Asia. Regulatory incentives to the recovery of by-products can make a positive difference in this case, but the main issue is if these investments are profitable enough to be developed in a more restrictive financial environment.

Options to blending copper concentrates impurities are available at a cost. One alternative is the expansion of current smelters that process complex concentrates, such as the operations at Alto Norte in Chile, Tsumeb in Namibia, Horn or XGC smelters in Canada. But the idea of locating polluting smelters in remote locations is not strongly supported by the industry as observed in the Kosaka smelter in Japan, and in the closures of la Oroya in Perú and San Luis de Potosi smelters that treated complex materials. A different alternative is to invest in modern technologies that are able to capture most of the arsenic in the gas instead of the slag, as observed in some of the new copper smelters in China. In this case the stabilization and safe disposal of the smelter dust becomes a subject to be regulated carefully. More roasters in copper mine sites as in Chile, and more hydro-metallurgy plants processing smelter residuals is a complementary possibility, as observed in CODELCO, Chile in recent years, combined with new high oxygen-blow smelters in mining regions replacing polluting technology as happened in China in the period 2006-2018.

Traders Response: Blending Clean and Complex Copper Concentrates. An increase in blending plants has been the response to copper concentrate impurities import controls in Asia. New copper concentrate blending plants were recently operational in Peru, Spain, in Chinese Free Trade Zones, and possibly in Malaysia in the near future. Even with a more copper miner friendly regulatory environment emerging in North and South America, social licenses and impurity issues in mines, plants and smelters will continue in different regions. Domestic value added and concentrates export tax regulations are expected to keep growing in South East Asia after the advances in Indonesia and Africa´s Copperbelt, increasing the cost of trading copper raw materials as copper concentrates.

Chinese Copper Smelters: Blending and Treating Residuals. Since 2016 China has allowed the set-up of copper concentrate blending plants linked to smelters in some Free Trade Zones. Chinese copper mining companies in Perú, Zambia and Congo DC produced around 1,280 kt in copper content in 2017. With more concentrate output and impurities in Chinese overseas miners, compliance with the impurity import limits has become harder to achieve. In June 2018, the new Ningde smelter started operations in China with an initial capacity of 200 kt rising to 400 kt. To make this possible in 2016 a Chinese blending plant for complex copper concentrates from Peru started operations in China Fujiang Ningde Port. However, clean and complex concentrate blending is not sustainable without a sufficient supply of clean copper concentrates.

Chinese Industry Response: New Smelting Technologies. In 2015-2020 recent research from ICSG consultants report copper smelting and emission control technologies moved to implement bath technologies such as TSL, Chinese bottom and side blowing and 2 STEP SLS+SLCR furnaces. In the case of more recent smelter technologies, all in China, more than 80% of arsenic goes to gas in wet concentrates processed in bottom or side blown copper smelting with no smelter dust re-circulated, as it is collected and treated to eliminate arsenic and recover valuable metals by other process streams. Some smelters in China started to use the Japanese copper sulfate process to recover arsenic residues in the 1990s, but this was considered a long process with high costs and ~45% of the arsenic was re-melted increasing the emission risks.

Chinese Copper Smelters Response: Residuals Recovery. In 2008, China started using arsenic sulphide pressure leaching plants with all the waste melted together in a side-blowing furnace including arsenic sulphide cake, black copper mud, flue dust and other waste, reducing costs and recovering more metal. Arsenic sulphide pressure leaching has been successfully operating in China Guixi copper smelter for 10 years, with arsenic leaching ratios of 95% and similar high rates for copper and rhenium with the leaching residue re-melted safely to recover Sb, Bi, Pb and S or removing arsenic from residue and using SX to recover the rhenium. A similar high pressure leaching plant in Tongling recently started operations and in 2018 it will start to recover small volumes of black copper and arsenic sulfide.

Chinese Commercial Response: More Imports of Copper Smelter Products. An alternative of Chinese copper processors to avoid local copper smelter production restrictions related to impurities and emission controls is to increase the imports of copper smelter products to be treated by Chinese copper refineries. This trend explains a much higher capacity of Chinese refineries when compared to smelter capacities in the past. This trend has created an international trade boom in copper anodes and blister copper. As a consequence the global trade of copper smelter products grew in recent years to achieve a peak in 2017, when copper blister imports into China achieved almost 800 kt, compared with only 530 kt in 2015. With the ongoing Chinese ban on low grade copper scraps and waste imports, is expected that this scrap be smelted outside China and exported to China as blister or anodes, but it is not certain, so in the meantime the copper concentrates imports remain vital for the Chinese copper processing and manufacturing industry.

Japanese Copper Smelters Hazardous Waste Management. According to MERI/J there are six copper smelters currently operational in Japan: Onahama, Saganoseki, Naoshima, Toyo, Tamano and Kosaka. In October 2018, some of these smelters discussed their arsenic management strategies and achieved some interesting conclusions that are summarized below.

- **Arsenic Management in Tamano and Saganoseki Smelters and Refineries.** Tamano copper smelter has a capacity of 200 kt/year meanwhile Saganoseki smelter has a 450 kt/year capacity. These smelters, managed by JX Nippon Mining, are currently facing an increasing arsenic to copper rate, in line with global arsenic content growth. In their Flash furnaces around 39% of the arsenic ends in the slag, which is sent to a slag cleaning furnace then granulated with water and used as iron silicate. However, the quality of the slag is falling as the arsenic content in the slag increases. Around 17% of the arsenic goes to copper matte, and 41% of the arsenic ends in the gas, with only 3% going to the smelter dusts. Dust and gas is washed and re-circulated to the Flash smelter, in the same way as slag and dust are treated in the anodes furnace, with lead residues with some arsenic (3%) going to a lead smelter. After the copper refinery tank house, less than 2% arsenic is re-circulated to the anodes converter, and the remaining copper rich arsenic sulfides and selenium residues, containing all together around 12% arsenic, are re-circulated to the Flash furnace.

- **Limits to Slag Use in Japan and Arsenic Removal Technologies**. Slag as iron silicate is used in Japan as fill material for artificial islands and as pillars in weak seabed stratum. But slag must pass a quality test for sale for general uses with a arsenic limit of 150 mg of arsenic per kilogram of slag and a dissolution limit of less than 0.01mg/lt. The recent slag quality from the smelters is not passing the standard, so it is causing a problem for the all industry. The seashore applications of slag face a less strict limit of below 0.03 mg/lt of arsenic so smelter slag can be used in these applications. Besides the problem of high arsenic slags, increased arsenic inflows have increased the costs of reagents at the waste acid treatment plants and the electric costs of purification plants in the refinery tank house by over 21% in the last 10 years. In response to the challenges, JX-Nippon is now using two technologies to remove the arsenic. One is roasting the imported concentrates with calcine over 700 degrees Celsius, collecting the clean copper as sulfide with the removed arsenic from inert roasting immobilized as arsenic sulfide. The other technology is alkaline sulfide leaching of the enargite (Cu_3AsS_4) at 80 degrees Celsius, recovering the copper as precipitate copper sulfide and cooling to collect the 0.2% arsenic in the residue and producing biological scorodite.

- **Arsenic Management at the Toyo Smelter and Refinery in Japan.** In the case of Sumitomo´s Toyo copper smelter and refinery, they have 3 tank houses producing up to 450 kt of copper cathodes per year. The arsenic content in the process has increased over the past 10 years and looks to be correlated with the refined copper prices, increasing in 2009-2012 and then decreasing in 2013-2016 to increase again in 2017. In 2008, close to 85% of the arsenic in the Toyo smelter ended in slag, another 10% as arsenic trioxide, 3% as slag powder and only 1% was lost in the flue dust. In 2018, around 99% of the arsenic is end up in the slag and 1% in other uses, with 31% of the arsenic from flue dust treated in the sulfuric acid plant and moved to a sulfuration plant where it is recovered as copper sulfide precipitate. It is then recirculated to the Flash furnaces with the usual residuals from the converter. As expected with more arsenic in the concentrates, both anodes and slag are more contaminated with arsenic, in the same proportion of arsenic inflow changes in 2007-2017. With 99% of arsenic in the slag, the use of the slag is restricted, with 69% of Toyo slag being used as cement industry raw material. In the copper refinery, around 80% of the arsenic in the anodes is dissolved in the electrolyte and the remaining 20% forms arsenates with Sb and Bi and ends in the refinery slime. The first impact of more arsenic causes increases in the electrolysis voltage, and the second impact is to create a white solid material that forms in the refinery pipes, so it is necessary to adjust the arsenic input for slag quality control and efficient refinery operation. Sumitomo Metal Mining Co's conclusion was that it is desirable for arsenic to be separated at the copper mine site, so arsenic does not reach their smelter and refinery operations in Japan.

- **Arsenic Management at the Naoshima Smelter and Refinery.** This copper smelter is managed by Mitsubishi Materials and reported an important increase in impurities and arsenic in particular for the period 2013-2014. Because the smelter increased the use of recycled e-scrap and waste materials, the total arsenic input has decreased since 2015. Currently this copper smelter is processing around 660 tonnes of arsenic per year, 86% from copper concentrates, 3.6% from recycled materials and 7.5% from other sources. In 2016-2017 close to 84% of the arsenic processed in Naoshima smelter ended as copper slag, almost 14% in other uses and 2.4% in copper anodes.

Mercury in Copper Concentrates and Smelters Regulations in Europe. Even when considered a minor problem compared with arsenic in Japan, mercury content in copper concentrates increased worldwide by almost 100% over the period 2012-2016 and might face more regulatory pressure as the Minamata Convention is implemented. In the European Union, the regulatory pressure on arsenic and mercury air and water emissions has been coincident with more blending of complex concentrates in Spain in particular. With the Minamata Convention compliance ahead in the EU and elsewhere, high mercury copper concentrates might be classified as "mercury waste", making their trade more expensive. Mercury thresholds are expected to be defined by the Minamata Conference of the Parties. In 2018, the Compliance Committee of the Convention became operational. To implement the United Nations Minamata Convention on Mercury agreed in 2013, the European Commission put forward, on 2 February 2016, a proposal for a regulation on mercury going beyond the current Mercury Export Ban Regulation No 1102/2008. The approved proposal introduced a series of additional provisions seeking to address certain 'regulatory gaps' identified by the Commission between EU legislation and the Minamata Convention. These issues are the core content of the law, including a ban on mercury imports, with wide exemptions; a ban on the export, import and manufacturing of a range of products containing certain levels of mercury, as of 1 January 2021. The regulation included restrictions on the use of mercury in certain manufacturing processes; a ban on new mercury uses in products and manufacturing processes already effective as of 1 January 2018. Steps to reduce mercury uses in artisanal and small-scale gold mining and restrictions on the use of mercury in dental amalgam as of 1 January 2019. The regulation published in the Official Journal as Regulation (EU) 2017/852 has been enforced since 1 January 2018.

Removing Arsenic and Other Impurities in the European Union. Copper smelters emissions of impurities are facing more restrictive social and governments licenses. Examples of this can be found in India, China, Chile and also the European Union in 2018. With more complex concentrates, the blending response is expected to face more regulatory constraints, so forward looking smelters are studying the re-design of poly-metallic treatment. In the case of key European copper smelters, where arsenic emissions have remained flat at around 0.9 grams per tonne of copper output in the period 2006-2016, the development of more modern smelters in the manufacturing regions is expected to face increasing restrictions concerning international transport and trade of complex copper concentrates. As a consequence, additional CAPEX to improve the capture of arsenic can be a limited solution in the face of shortages of concentrate supply, so alternative processing prior to smelting and even direct leaching can be more effective than blending and exporting to smelters. Low cost atmospheric partial leaching before smelting and even before exporting is raised as an option by the European experts.

Hydro Metallurgic Solutions: A Complement to New Smelting Technologies. As observed in China and in Chile, hydro metallurgic solutions to manage smelter dust and other solid and liquid effluents can be helpful as far as no additional impurities are re-circulated. The high arsenic and other impurities content in the slag are related to the smelting technology, so it might be better addressed by reducing the inflow of impurities in the concentrate before smelting. Alternatives to chalcopyrite copper concentrate treatment might be considered for treating high arsenic concentrates in the future. Hydro metallurgical technologies to extract copper from copper arsenic concentrates such as enargite exist, using pyrite or activated carbon to extract copper. These technologies can be combined with arsenic precipitation and stabilization (Fe-As) such as those developed by companies like Ecometales, Dowa and Outotec. Copper industry hydro metallurgists agree that the best place to treat arsenic is at the mine site to minimize the dispersion of the impurity, with hydrometallurgical extraction and precipitation having a complementary role limited by the cost of the technology.

Removing Arsenic from Copper Ores: JOGMEC Research Projects in Japan. Japan Oil, Gas and Metals National Corporation (JOGMEC) is advancing with research projects in cooperation with Japanese universities and mining companies on arsenic reduction. The main aim of these projects is the development of new processes for arsenic removal at the mineral processing stage, including a safe storage of the residuals. The first process is comminution to promote mineral liberation. One of JOGMEC research activities is to use high pressure grinding rolls, with which ore is ground at high pressure. The other processes under development include magnetic separation of ores, the development of new flotation reagents to capture arsenic and the treatment of complex concentrates by leaching.

- One of the most advanced JOGMEC projects is based on the upstream physical magnetic separation of copper sulfides such as chalcopyrite and bornite from arsenic rich enargite and tennantite sulfides, all with similar flotation behaviour. The process requires the grinding of high arsenic minerals at pressures 5 or 10 times higher than in conventional mills and then the development of a new flotation reagent with a bio substance that can modify the surface of the arsenic particles. The arsenic containing mineral then can be treated with high pressure leaching and bioleaching technologies.

- Also as part of JOGMEC's arsenic removal efforts in Japan, the National Institute of Advanced Industrial Science and Technology has tested a process to remove the arsenic from copper ores using a magnetic separator to split the copper ore containing arsenic. Preliminary findings show that the success rate depends on the chemistry of the mineral samples, so the challenge is to have a complete global detailed classification of copper ores. In the mean time the norm will continue to be the treatment of smelter flue dust and other residuals to produce crystalline iron arsenate (scorodite) as it is the least soluble of arsenic compounds.

Regulations on Hazardous Copper Industry Impurities in Materials. Recent **s**tudies on applications of copper industry impurities had been developed by the Institute of Multidisciplinary Research for Advanced Materials (IMRAM) at Tohoku University in Japan, whose recent findings are summarized in this section. The UN sustainable development goals propose the use of materials free from hazardous elements, whose use is already restricted in some regions. In the EU, the regulation on hazardous substances (RoHS) limits the use of mercury and lead to less than 1000 ppm (except for batteries) and the use of cadmium to less than 100 ppm. Meanwhile the EU REACH regulation limits the use of arsenic compounds in materials to less than 1000 ppm. The Joint Industry Guide regulates materials composition declarations for "electro-technical products" limiting the use of cadmium to less than 100 ppm and the use of As, Hg, Pb, Be, Sb, Bi and Se to less than 1000 ppm (JIG 2011). This regulation has driven substitution of these materials in batteries, solar cells, batteries, solder and fluorescent lamps in recent years, so the amount of these elements consumed by society in new products has been decreasing.

Arsenic and Cadmium Applications in Solar Cells and New Materials. Meanwhile the copper and zinc industries output of these elements has been increasing and some elements classified as hazardous contained in copper concentrates are in demand for the production of new materials such as solar panels for large scale solar power stations. This is the case regarding solar cell related materials as cadmium telluride (CdTe), whose raw materials are mining by-products and residuals produced in plants in Germany and Malaysia. Another promising application of copper industry residuals is the case of gallium arsenide (GaAs) for the production of thin solar cells, a product with the highest efficiency in the solar power production. The application of indium arsenide in the production of quantum dot solar cells might increase the sun to electricity conversion efficiency by up to 40%. In 2005 photovoltaic specialists in universities in France studied the semiconducting properties of the enargite (Cu3ASS4), and in 2016 universities of the United States analysed the photo chemical performance of enargite. A Tohoku university 2018 report suggested a high conversion efficiency versus GaAs solar cells. Semiconductor properties for cadmium arsenide (Cd3AS2) used in nano-wires was studied in 2015 by Oxford University researchers, and recent

MIT research revealed that cadmium arsenide had properties of an infrared light emitter. All the above elements might be used in functional new materials. However these materials are not to be used in consumer products with their use strictly controlled in order to be socially acceptable.

Possible Actions for ICSG Members

1. **Information on Impurities Capture, Disposal, Use and Regulatory Approaches.** Different industry and government parties have promoted the idea of having more international seminars on impurities in concentrates of non-ferrous metals. One of the topics of technical discussion is on the capture of arsenic, mercury, cadmium and other impurities. Another topic is what the industry can do with the arsenic and other impurities once captured. How the governments and international organizations produce regulations, guidelines and policy tools to achieve both objectives is a third dimension. One important additional area of investigation is how to advance the development of high and low technology new uses for arsenic and other impurities. There is agreement that more clarity is now necessary to quantify the total volumes of arsenic and other impurities in the supply side of the copper value chain. The surplus of impurities, and arsenic in particular, might be of an order of magnitude higher than the potential markets for new uses.

2. **An International Inspection System for Arsenic and Other Impurities.** In a JOGMEC organized conference on impurities in copper concentrates in October 2018 the Metal Economics Research Institute of Japan (MERI/J) proposed the development of an inter-governmental approach to track the flow of hazardous impurities in the international flow of copper raw materials, that might be extended to concentrates of other non-ferrous metals. MERI/J, with the support of JOGMEC and Japanese universities, proposed an international inspection system for arsenic. They proposed to approach the United Nations and governments in order to establish an International Inspection System for Arsenic. According to MERI/J, just like the Minamata Treaty, governments have to make such a regulation as soon as possible to avoid a major environmental problem of arsenic pollution. There is agreement that first parallel steps for this effort should be the compilation of very detailed data on volumes of copper concentrate impurities produced, traded and disposed of worldwide with regard to the most hazardous minerals including arsenic, mercury, cadmium and other impurities.

3. **Safe Stabilization and Disposal of Copper Industry Arsenic Residuals** The need for the development of crystaline scorodite production plants in Chile, Peru, Japan, China and Europe was also proposed by Japanese research organizations in October 2018, and is expected to be discussed with the governments and the non-ferrous metals industry operating in those countries. A more ambitious objective for preventing the international diffusion of hazardous impurities treating more residuals upstream has been mentioned as desirable by Japanese research centres and universities, but it is not still part of the formal objectives of the copper industry and related governments. Equal attention is expected to be paid by governments and industry to the methods of disposal and storage of arsenic compounds produced in previous decades that need to be closely tracked to reduce risk of spills and accidents. This includes the case of copper arsenide, calcium arsenate, particularly arsenic trioxide that is soluble in water and arsenic sulfide that can change into carcinogenic arsenic trioxide when exposed to air.

4. **Agreements in Relation to Copper Industry Impurities.** There is agreement between the community of industry experts in copper metallurgy on the need to improve the basic public data related to arsenic, mercury, cadmium and other impurities, not only in copper concentrates, but also from other sources. The lesson from the copper industry impurities seminars and technical discussions in 2017 and 2018 is that the situation is more challenging for copper smelters than before. The only chance to solve the copper concentrates impurities issue is by copper miners and copper smelter professionals worldwide increasing cooperation and looking for effective solutions. Not all agree that the best solution for the problem of impurities is to extract the arsenic and other minor minerals as close to the copper mines as possible, and to use only very clean concentrates in flotation, hydro metallurgy plants, copper smelters and refineries. More hazardous materials are being treated by the above mentioned plants in recent years and probably will continue flowing even in blended copper concentrates from mining districts to countries with copper smelters capacity importing copper concentrates. There is more agreement on the need to advance in a more controlled system of good practices, monitored by a recognized international third party. Another area of consensus identified is the need to advance more in the understanding of the global market for copper concentrates and on the need to generate trust among mining, smelting and waste processing companies. Copper miners, traders of copper concentrates and copper smelters are either competitors or commercial counterparts. But are all facing the challenge of earning the social licenses to operate in different countries, so there is a common need to exchange practices and standards.

This insight was produced by ICSG secretariat in November 2018. Comments and additional information on the sources are available to ICSG member countries on request. Please contact Mr. Carlos Risopatron, Director of Economics and Environment, International Copper Study Group, email: risopatron@icsg.org