Processing of indium: a review

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Abstract

Indium is an important by-product of zinc metal processing operations. Indium and other metal values are recovered during the production of primary commodities such as zinc by means of complex procedures, many of which are proprietary to each producer. One zinc recovery method consists of the Waelz process followed by leaching and purification prior to electrolytic recovery of zinc as cathodes and subsequent containment of the indium fraction in residues. Related processes for recovery of lead and tin from smelters and refineries also provide indium and other compounds. Indium may be associated with other valuable elements such as vanadium, thallium, gallium and germanium, and cadmium. Typical sulphide-bearing host minerals consist of Sphalerite, Galena, and Chalcopyrite. The igneous intrusions in sedimentary formations may include other base metals such as copper, cobalt, and noble metals consisting of gold, silver, and platinum group metals. The review serves to assimilate the major highlights of this somewhat rare metal which has both strategic importance and is well suited to electronic applications. On a global basis, the writers are aware of 30 producers dedicated to the commercial production of indium metal. Countries such as Belgium, Canada, China, France, Japan, Russia, and the USA are the largest producers of indium while about ten other countries contribute smaller quantities for worldwide consumption. The supply and demand of pure indium products during the past 40 years has been erratic and subject to wide fluctuations in delivered price. The paper describes the sources and established industrial processes for recovery of indium originating from sulphidic materials and process reverts.

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Keywords: Electrometallurgy; Extractive metallurgy; Non-ferrous metallic ores; Hydrometallurgy

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1. Introduction

Indium represents a very minor percentage of the earth’s crust, its concentration is comparable to silver which is about 0.1 part per million. Some individuals indicate that the indium content ranges from 50 to 200 parts per billion in the earth’s crust while the average indium content of zinc deposits ranges from less than 1 to 100 ppm. Indium, In, atomic number 49 and atomic
weight of 114.82 is a metallic element which is part of group 13 in the periodic table and is normally trivalent in its compounds since these are the most stable (Indium, 2002). It is worth noting that indium does not occur in the native state and it is regarded as a semi-precious non-ferrous metal. Elements such as iron, silicon, oxygen and magnesium account for over 90% of the earth’s composition. Indium was discovered by Reich and Richter in 1863 during analysis of sphalerite ores at the Freiberg School of Mines in Germany but commercial applications were not employed until the year 1934. The name “indium” was attributed to the indigo-blue colour of its spectrum (Ullmann’s, 2001). Indium is a soft silvery-white metal with a brilliant lustre which is crystalline (Indium Properties, 2002). This metal consists of a mixture of 96% indium-115 and 4% indium-113 which are two isotopes. It can be deformed under compression almost indefinitely. Indium with a specific gravity of 7.31 can be subjected to almost limitless deformation due to its properties of being ductile and malleable. The pure metal emits a high-pitched “cry” when bent similar to tin. In general, indium improves the strength, hardness, and corrosion resistance of alloys. Apart from its unique physical properties of a low melting point (156.6 °C or 429.8 K) and high boiling point (2353.2 K) indium becomes superconducting at 3.37 K (Felix, 1990). It is interesting that an alloy containing 24% indium and 76% gallium is liquid at ambient temperatures. Indium metal will burn at red heat to form a yellow oxide (InO₃). Although indium metal is considered to have low toxicity, precautions should be taken since limited history is available describing its environmental impact and effect on the respiratory system (MSDS, 2002).

The three major end uses are derived from indium metal, its alloys and indium tin oxide (ITO). Indium is employed in the fabrication of germanium rectifiers, photo conductors, and thermistors (Economics of Indium, 1999). It can be evaporated onto glass and plated onto metal, thereby forming a mirror that is comparable to that made with silver but with greater resistance to atmospheric corrosion (Indium Metal, 2002). Both indium and gallium are able to wet clean glass and other substances to form a hermetic seal. Indium semiconductor compounds are used in infrared detectors, high-efficiency photovoltaic devices and high-speed transistors. The largest end use for indium is in thin-film coatings such as prevalent in liquid crystal display screens (LCD’s) used in computers, games, and CD/DVD players, flat panel (aka bed) displays, solar cells (e.g., copper indium diselenide), and electroluminescent lamps. Indium metal represents a small specialized sector of the world economy with the value of primary metal consumed in excess of ten million dollars in the USA. The two American companies involved in indium production are the Indium Corporation of America and Arconium Speciality Alloys located in Utica, NY, and Providence, RI, respectively (USBM, 1992). A typical American end use distribution consists of 49% in coatings, 33% in low melting-point solders (i.e., lead-free) and alloys, 14% in electrical components and semiconductors, while research and others account for the balance of 4%. Japan consumes the majority of indium by employing in excess of 50% of the worldwide output in its various industries. The consumption within Japan has risen over 100% during the past decade (Economics of Indium, 1999). The Republic of China is expected to increase its export level in the years ahead while conversely Taiwan may become a larger importer of indium tin oxide (ITO) as it gears up to produce a higher volume of thin film transistors (TFT). China has expanded its tin industry such that for all intensive purposes it can be regarded as the world’s leading producer and exporter (Humphreys, 2002). Hafnium is used as a substitute for indium alloys in nuclear reactor control rods. Tin oxide or silver/zinc oxide are lower cost alternatives for indium–tin oxide in transparent conductive coatings for glass. Gallium arsenide can substitute for indium phosphide in semiconductor and solar cell applications (Mineral Commodity Summaries, 1992).

Purity of indium is normally expressed as a minimum of 99.97%. Brown (1999) had tracked the price fluctuations during the period 1959–1998 inclusive and the cost varied from a low of US$2.50 to a high of US$17.00/oz when expressed in current dollars. The price volatility was attributed to primary factors such as supply and demand, significant recycling, and the amount retained in National Defence Stockpiles (NDS). The price remained quite steady during 1998 at about US$10/troy oz (Roskill, 1999). Current prices of pure indium metal ingots in January 2003 remained at the very low level of US$85 per kilogram (i.e. US$2.64/oz). Apart from the actual producers of indium located in many countries, several firms are engaged in the buying and trading of indium containing products in shapes such as ingots, rod and wire, foil, tubing, and powders. As an observation, the consumption of indium-bearing materials is directly proportional to consumer demand for either electronic goods and/or automobile and aircraft sales. The purpose of the review is to highlight major details of this element rather than the reader reviewing numerous authors. Apart from key physical and chemical properties cited herein, individuals may choose to investigate the reference list and obtain very specific data such as its enthalpy of fusion for example. An alternative is to purchase reports prepared by Roskill after their extensive research and analysis to provide a comprehensive insight into the sector under investigation. Apparently, the latest editions of Roskill publications may range from about US$700 to US$2000 for the “Minor Metals in the CIS (1997)” and “Economics of Indium (1999)” respectively (Roskill, 1999). Without
sounding facetious, the paper provides a readily accessible and affordable condensation of the pertinent facts regarding the procurement of indium and its disposition.

2. Sources of indium

Although indium is associated with tin, lead, copper, and iron ores it is most commonly found in association with zinc-bearing materials such as in solid solution in sphalerite. The most common mineral containing zinc is sphalerite (ZnS) which is often associated with galena (i.e., lead sulphide). Sphalerite is stable below 1020 °C while the second form of zinc sulphide (wurtzite) is stable at elevated temperatures. Zinc sulphides are found in ore bodies in association with limestone or dolomitic rocks. The sulphur-bearing zinc is often combined with iron and manganese with occasional inclusion of cadmium and mercury while lead and tin rarely are mixed in with the sulphides. Traces of indium, gallium, and thallium are found in the ZnS while the mineral may either be argentiferous or auriferous (Dana, 1951). The sulphide ores normally are the result of some igneous intrusion and replacement of sedimentary type rocks as typical in metamorphic deposits. Zinc sulphides are often found in association with pyrite, galena, tetrahedrite, chalcopryite, silver ores, calcite, barite, fluorite, and other sedimentary types. The highest known concentrations of indium are found in veins and sulphide ore bodies associated with tin-bearing minerals. A high-grade indium source is the Huari Huari zinc deposit within a sphalerite ore body in Bolivia. The main zinc-bearing minerals include sphalerite as found in Spain and Romania, Zincite and Franklinite as found in the USA, Skare Ofe in Peru, and Smithsonite in Namibia.

Although indium concentrations in ores normally range from 10 to 20 ppm, high levels are found within tin deposits located in both Cornwall (UK) and New Brunswick (Canada). About four million troy ounces per year of indium (i.e., about 113 metric tonnes) are presently produced in the Free World, while Canada currently produces in excess of one million troy ounces annually. Canada hosts the largest known reserves of indium and two additional potential sites are located at a tin-tungsten deposit in New Brunswick and a Cu/Zn ore body in Ontario. Canada’s indium output is derived from two producers; namely, Teck Cominco Ltd.’s zinc operations at Trail, BC, and Falconbridge Ltd.’s Kidd Creek Cu/Zn operations at Timmins, Ontario. The operations at Trail, British Columbia, have been producing indium since the 1940s. Teck Cominco Metals Ltd. presently produces in the range of 30–40 metric tonnes indium per annum although the plant’s nameplate capacity approaches 70 mtpa. Five indium processors are located in Japan while the Commonwealth of Independent States (CIS) accounts for another five sources of global supply (i.e., Azerbaijan, Kazakhstan, Russia, Ukraine, and Uzbekistan). Refinery global production in general has exceeded 230 tonnes per annum (tpa) during the past several years. Future global consumption may approach 250 tpa by the year 2005 (Economics of Indium, 1999). Existing world reserves of indium are adequate to meet the expected demand well into the next decade.

3. Commercial recovery processes

Indium is recovered upon processing base metal concentrates and it is recovered almost exclusively as a by-product of zinc. The metal which is softer than lead can be refined to purities of four nines (i.e., 99.9999%). Extractive metallurgy has been developed to recover indium from treatable residues (domestic and imported) which traditionally contain about 30% of the available indium. Improvements in recovery have increased indium extraction to approach 80%. Countries with limited mine sources domestically such as Italy, France, and Belgium refine indium from imported lead/zinc residues, flue dust and drosses. Although the majority of indium reports in zinc-bearing processes, the paper includes a brief description of indium extraction from lead and tin circuits for completeness. Within the CIS, elements such as indium, gallium and germanium, selenium and tellurium are classified as strategic substances and hence very little published information is available in the public domain (Minor Metals in the CIS, 1997). Cadmium is regarded as a vital material for military usage. Russian platinum group metals (PGM’s) and base metal output from Norilsk Nickel for example is a state secret and companies are forbidden to release actual production data (E & Mj, 1998). Table 1 was compiled to illustrate the 30 plants in 18 countries which generate indium as a by-product from primary metals production. It is noted that the Republic of China operates several State-owned refineries for non-ferrous metals; hence the figure is actually in excess of the 30 plant locations cited herein. Five of the world-wide indium producers are grouped within the CIS. It is worth emphasizing that many indium producers such as in the USA in fact treat indium-bearing materials such as residues unlike the large facilities in the Urals (i.e., CEZP) which actually recover metallic indium and cadmium as a saleable by-product from their zinc operations. Other companies are best described as indium processors since they produce indium alloys and shapes for the electronics industry rather than being directly involved in recovering indium from base metal concentrates. Several firms such as UMICORE, Belgium (formerly Union Minière), and Norddeutsche Affinerie AG (Germany) may either toll or purchase residues...
from other refineries (e.g., Savage Zinc) that contain valuable elements.

In one Canadian operation, the residue from metallurgical treatment is directed to a lead smelter where about one half of the indium reports to the lead bullion while the remainder is included in the blast furnace slag. Slag fuming is used to recover indium, lead and from the slag fraction. Upon processing the lead bullion, indium is obtained in the lead dross slag which is then electrothermally reduced into lead, antimony, tin, and indium bullion. Electrolytic operations are employed to produce an indium anode and a slime containing 20% to 25% indium. The slime is chemically treated to provide a crude indium metal about 99% purity. The impure metal is then subjected to further electrolysis to produce either standard (99.97%) or high purity grades of indium metal (99.999+%). At UMICORE (formerly Union Minière and MHO) facilities in Hoboken, Belgium, the Harris process is used to recover indium concentrates during the refining of lead. Lead bullion at the La Oroya smelter of Centromin Peru SA is first dressed to remove copper, then tin and indium are removed at higher temperatures. The Sn/In dross is reduced by means of coke followed by the addition of lead and zinc chlorides to recover InCl₃ in the slag. The chloride slag is leached by wet grinding. The resulting solution is next purified by cementation of tin and lead on an indium sheet while the indium is recovered as a sponge upon adding powdered zinc. Centromin is Peru’s leading producer of silver, lead and zinc.

In contrast, the treatment of indium in tin circuits involves the chlorination of electrorefined tin to produce a tin chloride slag containing less than 3% indium. This process is presently employed at Capper Pass in the United Kingdom. The majority of the tin is precipitated in two neutralization stages in series including recycling from the second stage. Cementation with zinc is used to recover indium as a sponge material. The 95% purity sponge is then electrorefined to produce a 99.5% purity indium cathode which in turn is recast as the anode to yield 99.97% purity indium metal in a second stage of electrolysis. Sponge indium ranging from 95% to 99.5% requires further refining to suit most applications. Electrorefining is applied to upgrade this impure form when producing indium of four nines quality (i.e., 99,9999%) as applicable within the semiconductor industry. At present, five separate grades of indium are commercially on the market which range from 99.97% (3N7) to 99.99999% (7N—i.e., 7 nines). Cotton-bagged indium anodes and pure indium cathodes are employed in the electrolytic process which generally involves a chloride solution although alternative electrolytes such as sulphates, sulfamates, and fluoroborate are technically feasible. The metallic impurities which report as a slime are collected within the anode bag. Electrolyte is quite acidic within the pH range of 2.2–2.5 and nominally contains 20–75 g/l of indium, 80–100 g/l of sodium chloride and about 1 g/l of glue. The cell’s current density ranges from 1 to 2 A/dm². Electrorefining of indium is difficult since many impurities associated with it have standard potentials similar in value to indium. The final product may contain either metallic and/or non-metallic impurities. The reference literature contains a number of papers describing the separation of

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**Table 1** Major producers of indium worldwide

<table>
<thead>
<tr>
<th>Country</th>
<th>Name of producers</th>
<th>Primary products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Pasminco Ltd.</td>
<td>Cu, Zn</td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>Gjandra Almina Refinery</td>
<td>Zn, Al</td>
</tr>
<tr>
<td>Belgium</td>
<td>UMICORE (formerly Union Minière)</td>
<td>Cu, Zn, Ga, Ge</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Comibol, Corp Minera de Bolivia</td>
<td>Sn, Pb</td>
</tr>
<tr>
<td>Canada</td>
<td>Teck Cominco Ltd.</td>
<td>Zn, Pb, Cu, Cd</td>
</tr>
<tr>
<td>Falconbridge Limited</td>
<td></td>
<td>Ni, Cu, Zn, Co</td>
</tr>
<tr>
<td>China</td>
<td>State-owned plants</td>
<td>Zn, Pb, Cu</td>
</tr>
<tr>
<td>England</td>
<td>Capper Pass Ltd.</td>
<td>Sn</td>
</tr>
<tr>
<td>Johnson Matthey Ltd.</td>
<td></td>
<td>Precious metals</td>
</tr>
<tr>
<td>France</td>
<td>Société Minière et Metalurgique de Pennarroya</td>
<td>Zn</td>
</tr>
<tr>
<td>Germany</td>
<td>Preussag GmbH</td>
<td>Zn, Pb</td>
</tr>
<tr>
<td>V.E.B.</td>
<td>Zn, Cu</td>
<td></td>
</tr>
<tr>
<td>Berzelius Metalhuetten GmbH</td>
<td></td>
<td>Zn</td>
</tr>
<tr>
<td>Italy</td>
<td>Pertusola Sud S.p.A.</td>
<td>Zn</td>
</tr>
<tr>
<td>Japan</td>
<td>Dowa Mining Co. Ltd.</td>
<td>Pb, Bi, Cu, Cd</td>
</tr>
<tr>
<td>Mitsubishi Materials Corp.</td>
<td></td>
<td>Zn, Pb, Cd</td>
</tr>
<tr>
<td>Mitsu Mining &amp; Smelting Co. Ltd.</td>
<td></td>
<td>Zn, Pb, Cd, Bi</td>
</tr>
<tr>
<td>Nippon Mining &amp; Metals Co. Ltd.</td>
<td></td>
<td>Zn, Cu</td>
</tr>
<tr>
<td>Sumitomo Metal Mining Co. Ltd.</td>
<td></td>
<td>Zn, Cu, Co</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>Kazzine JSC</td>
<td>Zn, Cu, Cd</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Billiton plc</td>
<td>Precious metals</td>
</tr>
<tr>
<td>Peru</td>
<td>Centromin Peru</td>
<td>Zn, Pb, Cu</td>
</tr>
<tr>
<td>Russia</td>
<td>Chelyabinsk Electrolytic Zinc Plant</td>
<td>Zn, Pb, Cd</td>
</tr>
<tr>
<td>Krasnoyarsk Non-Ferrous Metals Plant Co.</td>
<td></td>
<td>Precious metals</td>
</tr>
<tr>
<td>Novosibirsk Tin Works Podolsk Chemical-Metallurgical Works</td>
<td>Sn, Bi</td>
<td></td>
</tr>
<tr>
<td>Sb, Ga, Ti</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ukraine</td>
<td>Konstantinovka Mill (Uhrzink)</td>
<td>Pb, Sn, Cu</td>
</tr>
<tr>
<td>United States</td>
<td>Indium Corp. of America</td>
<td>In</td>
</tr>
<tr>
<td>Arconium Specialty Alloys</td>
<td></td>
<td>In</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>Almalyck Mining &amp; Metallurgical Complex</td>
<td>Zn, Cu, Cd</td>
</tr>
</tbody>
</table>

indium from non-ferrous metals such as tin, copper, and zinc, plus elements such as gallium and germanium. Extraction may be carried out in either an alkaline or acidic medium using various chemical agents.

The recovery of indium metal from zinc circuits requires different methodology than other sources containing tin and lead. The literature illustrates the simplified flowsheet at Anaconda’s former operations at the smelter located in Butte, Montana (Felix, 1990). As a historical perspective, Atlantic Richfield Co. (ARCO) bought the holdings of the Anaconda Copper Mining Co. in the 1970s and this area is now designated as a Superfund site for environmental clean-up. An active processing site consists of Mitsubishi’s 1972 vintage Iijima zinc refinery at Akita, Japan, which treats indium-bearing residues. This plant is associated with the Mitsubishi lead and tin smelter/refinery complexes located at Hosokura and Ikuno respectively. Fig. 1 depicts the treatment of residues at Mitsubishi’s Akita zinc smelter and refinery to recover cadmium by-product and concentrate the indium fraction for subsequent recovery (Mitsubishi, 1984). At Akita, the zinc residue containing about 120 ppm indium undergoes a sulphation roasting process followed by sulphuric acid leaching to provide a solution containing indium in the range of 50–70 mg/l. Calcium carbonate is used in a two stage neutralization to concentrate the indium content to about 2 g/l. Solvent extraction produces an aqueous solution containing 20–30 g/l indium into which aluminum plates are immersed. The indium sponge adhering to the aluminum plates is removed then cast into anodes for subsequent electrowinning to produce indium metal of 99.99% purity (Felix, 1990). Another typical circuit to recover indium from zinc oxide involves leaching with dilute sulphuric acid to dissolve the indium. Neutralization to pH 1 allows tin to be removed from the leach liquor while additional neutralization causes the indium to precipitate. The indium-bearing residue is next leached with sodium hydroxide to provide indium hydroxide as an intermediate product which is directed to a dissolution step with dilute hydrochloric acid. This step results in an indium solution which is purified by employing iron to cement out the copper and arsenic, followed by cementation of lead and tin by means of indium. Cementation with aluminum allows recovery of the indium from solution. Indium is recovered from Falconbridge Ltd.’s Kidd Creek Cu/Zn operations located in Ontario, Canada. Although the original plant design capacity was 30 metric tpa of indium, the process can accommodate a peak of 50 tpa depending upon factors such as impurity levels and the percent operating time. Falconbridge Ltd. installed a Mitsubishi continuous converting system at its Kidd Creek facility in 1981 to increase plant capacity for copper. The dirty off-gases from the copper smelter are directed from the balloon flues to an electrostatic precipitator (ESP) prior to recovery of sulphur as sulphuric acid (Newmand et al., 1992). Dust obtained from the precipitator in the copper smelter is slurried then transported by trucks to the indium plant which features a proprietary recovery process. However, a simplified process description follows to illustrate the basic steps involved. The initial low acid leaching step facilitates recovery of the majority of copper and zinc values contained in the smelter dust. After solid/liquid separation the residue is directed to a high acid concentration leach at high density to recover the remaining copper and zinc plus the indium. Following another solid/liquid separation stage the indium-bearing solution is subjected to a reducing environment which ensures that all the ferrous ions are converted to the ferrous state. The reduced solution becomes the feed stream for a solvent extraction circuit in which indium is collected and stripped into a pregnant solution containing a high concentration of indium. A purification step employing sodium hydrosulphate eliminates residual impurities. The indium is next sponged from solution and then cast into anodes which are electrowin refined. The final purity of the indium ranges from 99.998% to 99.999%. At present, annual production rates of indium metal at Kidd Creek are generally about 20 tpa which is contingent upon the concentration of valuable constituents in the ESP dust recovered in the smelter and actual equipment utilization (Pye, 2003). As a point of information the largest producers of zinc listed in priority consist of China, Australia, and Peru while conversely the largest consumers of zinc are the United States and China. On the basis of exports, China is the world’s second-largest exporter of zinc after Canada. It is noteworthy that although China has a 770 lead/zinc smelters in operation the average plant capacity is only 3000 tpa which is in contrast to the norm of 90,000 tpa for zinc in the West.

Fig. 1. Recovery of indium from residues.
Only 11 plants in China can produce more than 50,000 tpa of lead/zinc products which consequently may lead to some indium collection as a by-product (Humphreys, 2002).

The Joint Stock Company “Chelyabinsk Electrolytic Zinc Plant (JSC CEZP)” is located within the central Urals of the Russian Federation. The zinc smelter and refinery were established during 1935 within the City of Chelyabinsk which was established 250 years ago and currently contains a population of over one million people. The industrial plant property covers an area of about 65 hectares located less than 1 km west of the Miass River. The zinc works employ 2500 workers of which 1500 are in production along with 300 staff personnel (Moskalyk and O’Kane, 1994). The plant complex has continually improved the industrial facilities and processes by incorporating state-of-the-art technology as an ongoing corporate philosophy. Snamprogetti S.p.A. supplied the equipment and technology which was modelled after the zinc refinery in Porto Vesme, Sardinia, Italy which is owned by Nuova Samin. The plant’s initial nameplate capacity was 110,000 tpa of zinc which is primarily cast into regular ingots and secondarily into jumbo ingot shapes plus 8000 tpa as zinc alloys. In-house modifications during the past years enabled the plant to produce about 130,000 tpa depending upon concentrate availability. Reconstruction phases during the past decade have allowed the plant to achieve a 200,000 tpa level of SHG zinc cathodes as described in the discussion section. The Enterprise apparently accounts for over two thirds of the worldwide indium production and recovers metallic cadmium as a by-product. Process reverts such as a copper clinker containing significant amounts of precious metals are sold to a Russian copper smelter (Mednogorsk). By-products (indium, cadmium, copper clinker and lead paste) represent about 12% of the plant’s overall gross revenues when consolidated with zinc and alloy sales.

Chelyabinsk receives 80% and 20% of its required zinc concentrates from domestic and foreign sources respectively. The plant employs a fluid bed roasting process to convert the zinc sulphides to oxides for subsequent leaching while the roaster off-gases are handled in a double contact process acid plant for the manufacture of metallurgical grade sulphuric acid (H₂SO₄) which is used internally while excess acid is sold within Russia. The proven Waelz process is used for the treatment of lead residues and the high precious metals content of the feedstock. The thickener underflow from acid leaching is filtered, dried then passed through large kilns. Other plant processes following the roasting step involve leaching and purification, gas cooling, electrolysis and melting, then packaging and shipping. The leaching and purification area includes a separate building for the production of indium. This metallic product is cast as one kilogram ingots which are sold to manufacturers of semiconductors and bearings. The proprietary process developed internally also produces lead paste as a revert which is sold to lead smelters. Although many references in the published literature are no longer applicable or relate to mothballed plants, the CEZP facilities for indium in the Russian Federation are actively producing product for global distribution.

4. Discussion

Although a portion of the indium in zinc circuits is recovered by cementation with aluminum, electrolysis is the main process in zinc, lead, and tin refining for producing metallic indium. For example, two stages of electrodeelectrorefining are employed in tin processing operations such as at Capper Pass located in Humberside, England. Firms such as Johnson Matthey are engaged worldwide in the recovery of speciality and precious metals. At present, in excess of 80% of worldwide zinc production originates from electrowinning techniques which represent the majority of indium output as a by-product. About one quarter of the world’s electrolytic nickel production is electrowon, 100% of all electrolytically produced cobalt is electrowon, while approximately 20% of global copper is derived from SX-EW operations (Moskalyk and Alafantazi, 2002). Electrolytic techniques such as either electrorefining or electrowinning as applicable are employed to commercially recover other minor metals such as cadmium, silver, magnesium, and manganese. One writer conducted a comprehensive survey of worldwide metal refining facilities. Zinc refineries total in excess of 85 plants on a global basis. Asturiana de Zinc’s facilities located at San Juan de Nieva in Spain are the most modern in the world (E & Mj, 2001). It is noteworthy that zinc refineries dominate lead and tin electroweining plants by a ratio of roughly 2:1 and 10:1 respectively (Moskalyk, 1999). However, primary and secondary smelters coupled with refineries are found in 59 countries for lead while 36 countries include zinc processing facilities (Burrell, 2002).

Indium reports in various base metal concentrates, residues other reverts and process wastes (e.g., metallurgical slag) thereby becoming potential sources of supply once a recovery process is initiated (Thibault, 1988). For example, the Clarksville plant in Tennessee has a capacity of 105 K-tpa zinc. This zinc smelter and refinery which was acquired from Savage Resources in 1999 ships its residues containing indium, germanium etc. to UMICOORE (formerly Union Minière) in Belgium for processing. Pasmusco Ltd. (Australia) acquired the Clarksville zinc smelter (E & Mj, 2002a,b). Refineries either toll this material or sell it directly to another producer which has facilities to handle these zinc impurities. The first stage of the Huaxi metallurgical plant was recently completed and commissioned at Laibin,
Guangxi, in the Republic of China. The first phase capital expense amounted to RMB 350M (renminbi). The indium and tin project is reported as being one of the largest facilities in the world. The plant expects to produce 41 metric tpy of indium (E & Mj, 1999). The American Metal Market (1998) indicated that the national defence stockpile of indium was depleted in 1998 upon sale of Defence Logistics Agency (DLA) to Wogen Resource Ltd., London (8k troy oz) and Euromin SA, Geneva (6.2k troy oz). Novosibirsk in the Russian Federation has developed an apparatus to recover indium from raw lead/tin materials by means of vacuum refining (Novosibirsk, 2001). Old established plants such as Preussag AG Metall in Germany recover a multitude of elements from concentrates and scrap such as zinc, lead and tin, cadmium, antimony, indium and indium alloys, bismuth, thallium, mercury, selenium and tellurium, and arsenic which are marketed in a variety of shapes such as ingots, bars and rods, granules, foil, sheet, strip, wire, and powders (Non-Ferrous Metal Works of the World, 1998, 1982).

ZincOx Resources Plc has entered into an agreement to acquire a 51% interest in the slag dumps at the old Tsumeb mine in Namibia. The dumps total 2.9Mt of slag containing zinc (9.03%), lead (2.05%), germanium (0.026%) gallium (approximately 0.02%) and indium (approximately 0.017%) with a combined value of more than US$1-billion. Preliminary metallurgical test work has demonstrated that the metals can be concentrated into an oxide dust by reduction and fuming. A technical study was completed by Korea Zinc to examine the Tsumeb slag project. ZincOx carried out a preliminary economic appraisal of the project in the first half of 2002. Development will be carried out jointly with Onegopo Mining & Processing Ltd, who are current owners of the dumps and infrastructure. The engineering study concluded that the Tsumeb slag can be processed by means of Ausmelt furnace technology to produce an oxide fume which concentrates zinc, indium, lead, gallium and germanium. The recovered concentrate would be sold to others for further refining. The Tsumeb slag accumulated during lead smelting operations between the period 1963 and 1996. The resource, consisting of metallurgical slag, is estimated at million metric tonnes. Ausmelt Limited, based in Victoria, Australia, anticipate that indium recovery from the slag will be about 75% and grade 170 ppm in the concentrate (E & Mj, 2002a,b).

Chelyabinsk zinc expected to bring 200 K-mtpa modernized electrolytic zinc capacity into production by early 2003. The 10 year old plan had involved a signed contract with Italy’s SNA (i.e., Snamprogetti) but had waited and equipment was not fully installed (stored on plant site) due to lack of funds. Outokumpu Engineering (Finland) replaced SNA and carried out the refit. Investment for the expansion totalled $19M and $30M for the years 2000 and 2001 respectively. CEZP is controlled by London (UK) based Euromin which is affiliated with Vitol SA (registered in Switzerland). Euromin paid $35M to buy shareholding control of Chelyabinsk in the mid-1990s. CEZP receives 80% of its zinc concentrate from three Russian regions; namely, Bashkortostan, Orenberg, and Chelyabinsk while the remainder is imported. About 70% of the company’s sales are directed to Russian domestic buyers, which mainly consist of steel plants for galvanizing (E & Mj, 2001). As a concluding observation, the global indium industry appears to be in a phase of sustained growth which is attributed to the inception of new sources of supply coupled with improved extraction efficiencies. One analyst commented that high-technology consumers will enable the indium commodities sector to expand at an annual rate ranging from 15% to 20% (E & Mj, 1999). It is apparent that world consumers may be assured of an adequate supply of indium albeit at a variable realized price which is related to the quantity and and grade as evidenced over the years.

References


