

An Overview of Copper Smelting in Southern Africa

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Copper and copper alloys remain key materials for society today, with important uses found in the electrical, transportation, and construction industries. Copper demand is rising, with projections indicating that by 2025 global refined copper demand will increase to 29.5 million tons, up from the 22.4 million tons anticipated for 2015. This will require the opening up of dozens of new mines and numerous new smelters over this time period. Fortunately, Africa has significant reserves of copper, and African copper can once again play a key role in contributing to meeting the rising global demand for copper. This paper provides a brief overview of the current copper smelting operations in Southern Africa.

INTRODUCTION

Copper and copper alloys are essential materials for today's modern world. The familiar green copper patina colour seen on buildings and other structures sometimes belies its true "green" characteristic – copper is essential for key emerging technologies such as wind turbines, tidal generating systems, solar energy systems, electric cars and the like. Consequently, it is believed that there will be continued growth in copper demand in the years ahead. Projections indicate that by 2025, as an example, global refined copper demand will increase to 29.5 million metric tons, up from the 22.4 million ton level anticipated for 2015. This will require dozens of new mines, and of the order of the equivalent of 10 to 12 new 0.5 million tons of copper/year-sized copper smelters (after factoring projected copper produced by electrowinning (EW)) – overall, a huge undertaking. Fortunately, Africa has significant reserves of copper, and African copper can once again play a key role in supplying this rising global demand for copper. Africa's share of global mined copper production was about 10% in 2014; however this will increase significantly in future if announced new projects eventuate. Southern Africa has an important role to play in this process. The present paper provides a brief overview of copper smelting in Southern Africa.

Ancient History of Copper Smelting

Smelting history goes back at least 6000 years to the copper smelters of the Timna valley near Eilat in Israel. Copper is the world's oldest metal and was used more than 5000 years ago for water plumbing in the Pyramid of Cheops in Egypt. The Egyptians obtained their copper from Israel and from Cyprus. Throughout the second millennium BC, copper was produced in Cyprus by extracting it from copper sulfide ores. The ancient Cypriots pioneered pyrometallurgical processing of copper, using the surrounding forest to supply energy for the process, and adding fluxing materials from areas close to the mines. Later, tin was found in the Iberian Peninsula, and it was possible to produce a copper-tin alloy (bronze), which was used in the manufacture of tools, implements, weapons, and ornaments. A comparison between the chemical composition of typical massive sulfide ores and ancient slag from Cyprus clearly suggests that in the smelting process the metallurgists mixed the ore with silica and manganese-bearing rocks (probably umber) to lower the melting point and regulate the viscosity of

the melt, making it easier to separate the metal from the slag. The smelting of copper sulfide ores in Cyprus lasted for more than 3500 years and produced more than 200 000 tons of copper metal. Many slag heaps remain to this day.

O'okiep Copper Company

By contrast, the earliest records of large-scale copper production in South Africa date back to the second half of the 1800s when the Cape Copper Company began smelting copper ore from Namaqualand. The indigenous African people in the area had probably worked copper in Namaqualand for several hundred years, but this was necessarily done on a small scale. Dutch colonialists discovered the Okiep deposits in 1685, when Simon van der Stel discovered the 'Copper Mountain' at Springbok, after officials at the Cape learnt of the existence of copper, somewhere to the north, from Namas who brought objects made of that metal. However, transport and other difficulties prevented exploitation at that time. The first South African mining company was formed there in 1852 to mine the copper deposits. Other notable firsts for this mining district include the first South African geological report and geological map, both of which describe and depict the Namaqualand copper fields. The Blue Mine, on the outskirts of Springbok, was the first mine to be sunk in the district (in 1852). The first records of the Okiep mine are dated 1856, when a shaft with a "splendid show of copper" can be found mentioned. In the 1860s, Okiep became the most important mine of the Cape Copper Company. In 1866, a narrow-gauge railway line was built to Port Nolloth on the coast. This line was primarily used to convey the partially smelted copper matte to the coast from where it was exported for further refining in South Wales. Because there was an insufficient supply of water to operate steam locomotives on this line, the service was pulled by mules until as late as 1890. An account of the mine (from a publication of the Colonial Office of the Cape of Good Hope dated 1878) indicates that the ore contained an average of 32% copper, and that cupola furnaces were in place. Production by the Cape Copper Company ceased in 1919 as a result of the post-war economic slump, and Okiep soon became a ghost town. The operations of the Namaqua Copper Company continued for slightly longer, but its mines finally closed in 1931. The O'okiep Copper Company Limited was later formed in 1937 and acquired the assets of both the Cape Copper Company and the Namaqua Copper Company. Fluctuating copper prices, coupled with a remote and hostile setting, have resulted in varying degrees of success and failure in the 150-year modern history of the Okiep district mines (Smith, 2006). In 1984, Newmont sold the Okiep Copper Company to Goldfields of South Africa.

More recently, assets from the O'okiep Copper Company were acquired by Metorex in 1998. Reprocessing of the slag dump over a seven-year period by flotation methods started in 2002. Metorex managed the mine and smelter, sourced concentrate feed for the smelter, and marketed the resulting blister copper. O'okiep smelted its own concentrate, as well as concentrate from Maranda and Chibuluma. Concentrate was converted to blister copper at the smelter, and the product was exported, with the metal being refined in Europe. In order to maintain smelter efficiency, a further 50 000 t/a of other concentrate material was required. These concentrates were imported through Cape Town, smelted under toll agreements, and returned to commodity traders by the same route (Mining Weekly, 2004).

Today, Okiep (its modern spelling) is a small ex-mining town that is going through tough times, despite having been, at the turn of the previous century, arguably the richest copper mining area in the world.

Nkana Smelter, Kitwe, Zambia

According to Cutler et al. (2006), the Nkana smelter in Kitwe, Zambia was commissioned in 1931, with two reverberatory furnaces, two Peirce-Smith converters, and blister casting facilities. In the first year of operation, blister production was 6000 metric tons. At the peak of production in 1971, when 330 000 tons of copper was produced, there were five reverberatory furnaces and five converters in operation, with a sixth Peirce-Smith converter undergoing maintenance. By the early 1990s, production had fallen to a level of about 200 000 t/a, and in 1993 fell again to around 130 000 tons.

By the mid 1980s, ZCCM (Zambia Consolidated Copper Mines) management realised that Nkana faced serious operating cost and reliability problems into the future, by continuing to run end-wall-fired reverberatory furnaces as the primary smelting units. The other driver for change was the need for additional acid for leaching of the Nchanga refractory ores to increase production of electrowon copper. The 1986 study team's recommendations were to retrofit two conventional reverbs with an oxy-fuel roof-burner system (commissioned in 1990), and install an El Teniente converter to convert matte plus additional concentrates to white metal. Some of the Peirce-Smith converters would be retained for the conversion of white metal to blister copper. It was anticipated that the retrofitted furnace would smelt 800 tons of concentrate per day, compared with 450 t/d with an end-fired furnace using 14 oxy-fuel burners and around 200 t/d oxygen. In the event, the design of the gas-handling system was sufficient only to handle a maximum of nine burners - around 500 t/d concentrate. The El Teniente Converter was commissioned in 1994. Reverberatory furnaces were the mainstay of production up until 1994, when an El Teniente converter (CT) was installed to upgrade reverberatory furnace matte to white metal, prior to converting in conventional Peirce-Smith converters. In 2000, a decision was taken to increase the proportion of concentrate smelted in the CT by introduction of bone-dry concentrate injection through the tuyeres. A flash dryer with a nominal capacity of 1200 metric tons per day of dry product, and associated tuyere injection system was commissioned in March 2004. Based on the projected concentrate arisings from the KCM mines into the future, as seen in 2004, it was decided to develop the CT to be the primary smelting vessel at Nkana, to handle a minimum of 1250 tons per day of concentrate, and to operate only one reverberatory furnace in slag-cleaning mode pending a full evaluation of alternative slag-cleaning technologies. The anticipated cathode production from Nkana was to be in the range 140 to 150 000 tons per annum. Vedanta took over as the majority shareholder in Konkola Copper Mines (KCM) at the end of 2004, and worked towards maximizing the available smelting capacity, taking it to 165 kt/a. The Konkola Copper Mines (Sterlite) Nkana Smelter was closed in 2009.

SOUTHERN AFRICAN COPPER SMELTERS CURRENTLY IN OPERATION

Kansanshi - Solwezi, Zambia

The Kansanshi copper smelter - the newest copper smelter in Zambia, and one of the newest in the world - is located in Solwezi, the capital of the North-Western Province of Zambia. The Kansanshi copper smelter utilises **IsaSmelt** smelting technology, and will process 1.2 million metric tons of copper concentrate per year, with an output of 300 000 tons per annum of blister copper. The plant consists of an IsaSmelt furnace, a matte-settling electric furnace, four Peirce-Smith converters and two anode furnaces. The smelter produced its first copper in December 2014. Refractory installation throughout the plant was completed in March 2015 by the Dickinson Group.

The Kansanshi plant was already a major producer of SX-EW copper when they chose to expand their operation by installing a copper smelter. One of the key benefits of this integration between hydrometallurgy and pyrometallurgy is the reliable supply of low-cost sulfuric acid (1.0 million tons per annum) to sustain the existing operations.

Kansanshi Mining Plc (which encompasses the smelter and the adjacent mine) is 80% owned by Vancouver-based First Quantum Minerals Ltd and 20% owned by Zambian mining parastatal Zambia Consolidated Copper Mines Investment Holding (ZCCM-IH). First Quantum invested over \$800 million to develop the greenfield copper smelter, which, as indicated above, is expected to produce more than **300 kt/a** of anode copper.

First Quantum has previously announced plans for the future expansion of their Kansanshi copper smelter. The first stage of the expansion project was envisaged to include an IsaConvert furnace for producing blister copper from crushed matte. Proposed plans to double the size of the smelter currently seem to be on hold.

Konkola Copper Mines Nchanga Smelter – Chingola, Zambia

Konkola Copper Mines plc, a unit of the Vedanta group, operates a new Outotec direct-to-blister smelter at the Nchanga plant, Chingola, Zambia. The smelter, which was commissioned in 2008, includes a new 112 t/h direct copper **flash furnace** plus all ancillaries and two electric slag cleaning furnaces for cobalt and copper recovery from the highly oxidized slag. The blister copper is tapped to anode furnaces for fire refining. The smelter has a nominal capacity of **300 kt/a** (Chikashi, 2011).

Mopani Copper – Mufulira, Zambia

Mopani Copper Mines commissioned their **IsaSmelt** plant at Mufulira in Zambia's Copperbelt during 2006. It was designed to initially smelt 650 kt/a of concentrate, with the potential to expand to 850 kt/a in the future. Mopani's Isasmelt plant replaced their existing electric smelting furnace, which in turn had been introduced in 1971 to replace the original reverberatory furnaces which had been used for smelting when the plant began in 1937. The plant comprises a new feed preparation system, electric settling furnace, waste heat boiler, electrostatic precipitator, gas cleaning plant, oxygen plant and acid plant. Improvements were also made to the converter aisle and anode plants. This project, on a brownfield site in a remote area, took 28 months from signing of the engineering and licence agreement to achieve the first feed on in the furnace in September 2006. The smelter underwent a shutdown and rebuild in June 2014. The smelter is owned by a joint venture company, Carlisa Investments Corporation, comprising First Quantum Minerals, ZCCM-IH, and Glencore. Copper production is estimated to be about **185 kt/a**.

Palabora Mining – Phalaborwa, South Africa

Palabora Mining Company is situated in the Limpopo Province of South Africa, adjacent to the Kruger National Park. The Palabora smelter commenced in 1966, and consists of a single coal-fired **reverberatory furnace**, three Peirce-Smith converters, two anode refining furnaces, a holding / scrap melting furnace and an anode casting wheel (Brazier et al., 2006). A sulphuric acid plant was installed to treat the off-gas and produce sulphuric acid. The smelter nameplate capacity was originally 80 kt/a, but was improved and upgraded to 120 kt/a by 1972. The plant was built to treat concentrate produced at the Palabora concentrator handling ore from the then new open-pit mine. In 2004, the smelter feed was supplemented with imported concentrates. The facilities at Palabora include the smelter and the copper electro-refinery plus a number of ancillary plants handling by-products.

Originally a joint venture between Rio Tinto and Anglo-American, the facility is now operated by a new consortium comprising South African and Chinese interests. Once described as “possibly the most productive single reverberatory furnace operation in the world” (Edge, 1979), the plant today is forging its new place in the smelting world and promises to continue the long tradition already established at Palabora. The nominal copper capacity at Palabora is **160 kt/a**.

Chambishi (China Nonferrous Metal Mining Group) – Zambia

Construction began on the Chambishi Copper Smelter of Yunnan Copper Corporation (YCC), located in the Zambian Copperbelt, in November 2006, and the smelter began producing copper at the end of 2008. The **IsaSmelt** smelter was initially designed to produce 150 kt/a of blister copper, but has since been expanded to reach **250 kt/a** of blister copper (which represents a smelting capacity of 750 kt/a of feed) (Alvear, 2010; IsaSmelt, 2015).

Dundee Precious Metals – Tsumeb, Namibia

The Tsumeb smelter complex was built between 1961 and 1962 and commissioned in 1963 by Tsumeb Corporation Limited under Newmont Mining. It featured an integrated copper and lead section (with refinery), and smaller plants that produced cadmium and arsenic trioxide as by-products. Production officially started in 1964. At that stage, the smelter produced more than 3500 tons of copper and 6000 tons of lead per month.

In 1988, the Tsumeb complex was taken over by Gold Fields South Africa and administered by Gold Fields Namibia. Approximately six years later, the lead smelter was closed permanently. In 1996,

Tsumeb's mining and smelting operations came to a standstill due to a prolonged labour strike. This ultimately led to the closure and liquidation of Gold Fields Namibia in 1998.

Since the closure of the well-known Tsumeb polymetallic smelter around 1994, the smelting plant has undergone a number of ownership and name changes – from Ongopolo Mining and Processing, to Namibia Custom Smelters (Weatherly International), and was bought by its current owners, Dundee Precious Metals, in 2010. The facility consists of two primary smelting furnaces, the old reverberatory furnace, as well as a refurbished **Ausmelt** Top-Submerged Lance (TSL) furnace, with Peirce-Smith converters used to treat the matte. The smelter was converted to a toll smelter at the beginning of 2009. It has the capacity to treat about 120 kt/a of concentrate. The smelter is one of only a few in the world which is able to treat arsenic- and lead-bearing copper concentrates, and is therefore able to conclude long-term favourable contracts to treat such concentrates. The smelter treats high-arsenic copper ores, from Bulgaria and elsewhere. About half the smelter feed comes from Dundee's Chelopech mine in Bulgaria, with additional feed sourced from a number of countries including Peru, Greece, Russia, Poland and several African countries. Both blister copper and arsenic trioxide (As₂O₃) are produced from the concentrates. The blister copper is delivered to refineries for final processing, and the As₂O₃ is sold to third-party customers.

A new oxygen plant was commissioned in 2010, delivering 170 t/d of oxygen to the TSL. It is reported that with a further increase in oxygen capacity, smelter concentrate capacity will increase to 240 kt/a. Blister copper produced in the Peirce-Smith converters is treated at third party plants for refining. Nominal capacity at present is about **40 – 50 kt/a** of blister copper.

BCL Nickel-Copper Smelter – Selebi Phikwe, Botswana

BCL is a mining and smelting company that began its operations in the late 1950s. The **Outotec flash** furnace at BCL commenced in 1973, treating Ni-Cu concentrates from the Selebi mining operations. The flash furnace, one of the largest units in the world in terms of physical size, treats 120 t/h of Ni-Cu concentrate. The produced matte is converted in one of the three Peirce-Smith converters, and slag is cleaned in one of two electric furnaces. Finished Bessemer matte is shipped to a number of refineries for metal recovery. Nominal copper output in Bessemer matte at BCL is about **30 kt/a**.

Rubamin – Likasi, DRC

Rubamin, an Indian mineral exploration company, has processing facilities in the Democratic Republic of Congo (DRC) and India. They operate a small smelter at Likasi, in the Katanga Province of the DRC, treating primarily malachite ore. The commercial production of copper blister started in May 2008, with the first-phase capacity of 4.8 kt/a. Rubamin's furnace operations in Likasi produce **20 kt/a** of blister copper from malachite ore. The facility has a power installation capacity of 20 MVA.

Copalcor – Germiston, South Africa

Copalcor is South Africa's largest secondary copper smelter and manufacturer of copper, brass and alloy solutions. It stated life as an offshoot from a company based in Birmingham, England. McKechnie Brothers was started in 1948 by John Rae, Tom Jones, Jack Morris and Hal Hastings, in Wadeville, Germiston. It produces a wide range of copper and brass products. The scrap-melting **induction furnaces** supply molten metal for slab casting, hot rolling and extrusion. In 2010, Copalcor installed a 1000 kW induction power supply for a three-ton furnace used to supply metal for a continuous vertical casting process. They also have a 1600 kW induction heating system. Copalcor's three furnaces provide the capacity to melt over 400 tons of non-ferrous alloys per month, roughly **5 kt/a**.

On the supply side, Copalcor also manufactures various furnace components, including busbars, contact shoes, furnace side-wall coolers, tap-blocks and launders.

Others

Not included in this overview are the platinum-group metal (PGM) smelters in South Africa and Zimbabwe.

CONCLUSIONS

Africa has significant reserves of copper, and African copper has once again begun to play a key role in contributing to meeting the rising global demand for copper. A number of plants with modern technology hold great promise. Currently, copper production capacity in southern Africa is around 1.2 million metric tons per annum.

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REFERENCES

- Alvear, G.R.F., Arthur, P., and Partington, P. (2010). Feasibility to profitability with copper IsaSmelt. *Proceedings of Copper 2010, Vol. 2 - Pyrometallurgy I*. GDMB, Clausthal-Zellerfeld, Germany. pp. 615–630. Available from <http://www.isasmelt.com/EN/Publications/Technical%20Papers/Alvear.pdf>.
- Brazier, D., Laing, W. and Nixon D. (2006). Transformation of the Palabora copper smelter to a toll/custom smelter. *Southern African Pyrometallurgy 2006*. Jones, R.T. (ed.). South African Institute of Mining and Metallurgy, Johannesburg. p. 249. Available from http://www.pyrometallurgy.co.za/Pyro2006/Papers/249_Palabora.pdf.
- Chikashi, H.M. (2011). Influence of slag composition on reduction control and operations of the slag-cleaning furnace at KCM, Zambia. *Southern African Pyrometallurgy 2011*. Jone, R.T. and den Hoed, P. (eds.). Southern African Institute of Mining and Metallurgy, Johannesburg. pp.185–198. Available from <http://www.pyrometallurgy.co.za/Pyro2011/Papers/185-Chikashi.pdf>.
- Cutler, C.J., Natarajan, M., Mponda, E., and Eksteen, J.J. (2006). Phasing out reverberatory furnace operations at KCM Nkana. *Southern African Pyrometallurgy 2006*. Jones, R.T. (ed.). South African Institute of Mining and Metallurgy, Johannesburg. pp. 251–264. Available from http://www.pyrometallurgy.co.za/Pyro2006/Papers/251_Nkana.pdf.
- Edge, D.A. (1979). Copper matte converting practice at Palabora Mining Company. *Copper and Nickel Converters*. Johnson, R.E. (ed.). TMS-AIME, Warrendale, PA, USA, pp.185–198.
- IsaSmelt (2015) Chambishi Copper Smelter. Available from <http://www.isasmelt.com/EN/Installations/Pages/Chambishi.aspx> [Accessed on 31 May 2015].
- Mining Weekly (2004). O'okiep Copper Company, South Africa. *Mining Weekly*, 28 May 2004. Available from <http://www.miningweekly.com/article/ookiep-copper-company-northern-cape-2004-05-28>.
- Smith, M. (2006). O'okiep & Port Nolloth. Available from <http://on-the-rand.co.uk/Base%20Metals/Okiep.htm> [Accessed on 31 May 2015].