Project Memo

PM1083-001-PC

ZINC ONE

Bongará Zinc Oxide Project

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Issue Date: 09 Aug, 2017

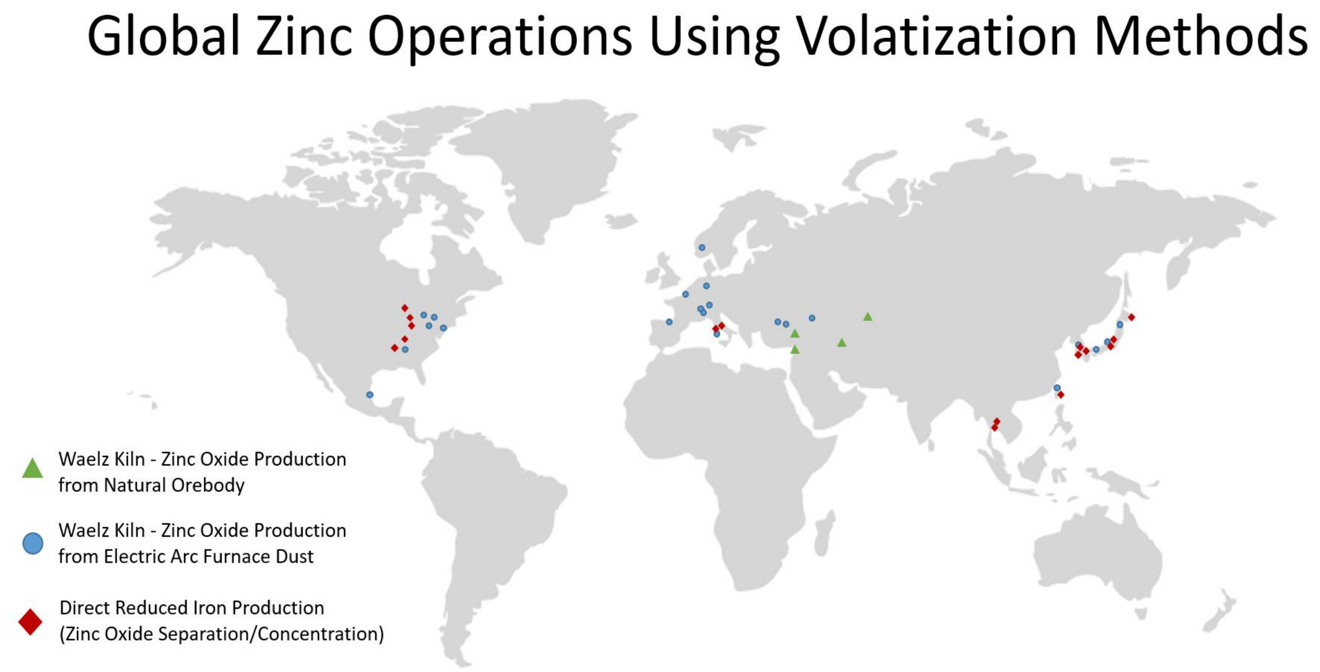
SUBJECT: **ZINC RECOVERY AND BENEFICIATION VIA VOLATIZATION - THE WAELZ KILN**

1. INTRODUCTION

Volatization and re-condensation of zinc as a method of zinc recovery and beneficiation is widely used in the steel and zinc industry (see Figure 1). The relatively high volatility of zinc compared to other metals such iron, lead, copper and aluminum, allows for zinc oxide to be effectively separated from a diverse array of zinc-bearing natural ore reserves, including oxides, sulphides, silicates and ferrites, and from zinc-bearing smelter residues, slags, slimes or from dust residues in the steelmaking industry – all by way of high temperature exposure. Typically this involves a carbothermic reduction with coal under negative pressure, with coal serving dually as the reductant and energy source, followed by a reversal of this reaction via the introduction of air into the later stage of the system. Temperatures of the reaction typically reach 1,100-1,250°C. Of most practical advantage, zinc volatization recovery methods can produce consistent product grades and recoveries from a diverse and variable feed grade. This, combined with the simplicity of construction and operation, and lack of water required, make volatization methods a particularly attractive option in zinc beneficiation projects.

The following map illustrates some of the zinc volatization recovery processes worldwide. One the most commonly used modern method of zinc recovery via volatization is the Waelz Kiln.

Figure 1



2. THE CARBOTHERMIC REDUCTION – GETTING ZINC TO ELEMENTAL FORM

Critical to the function of zinc volatization methods, and in fact to all of extractive metallurgy, is the carbothermic reduction process. A carbothermic reduction is a chemical reaction whereby an oxide mineral is mixed with carbon at high temperatures (often in excess of 500 °C). The mineralized oxygen reacts with carbon, forming carbon monoxide and/or carbon dioxide (depending on the conditions), leaving behind liquid metal. Often the reaction generates large amounts of heats (as does burning coal, for example), leading to a state in which the reaction is – to a point – self-sustaining. In each carbothermic reduction, there exists a minimum threshold temperature above which the carbothermic reaction will occur, as dictated by thermodynamics (similarly there is a threshold pressure but this is not commonly employed). Beyond the threshold temperature, the liquid-metallic phase is stable (i.e. at thermodynamic equilibrium). Once the liquid metal is separated, cooled and cast into solid form, the metal is now below the threshold temperature, and hence the original oxide form becomes the most thermodynamically stable form. Luckily, the relatively low temperatures of operation (albeit, with several exceptions (eg. jet engines)) and solid state of the metal slow the reversion reaction back to its original oxide form – i.e. the process of corrosion.

Carbothermic reduction is the one of the most ancient and still most widely used method of extractive metallurgy. Today, at least the following metals production involve a carbothermic reduction.

- Steelmaking
- Zinc
- Tin
- Titanium
- Lead
- Silicon
- Manganese
- Antimony
- Germanium

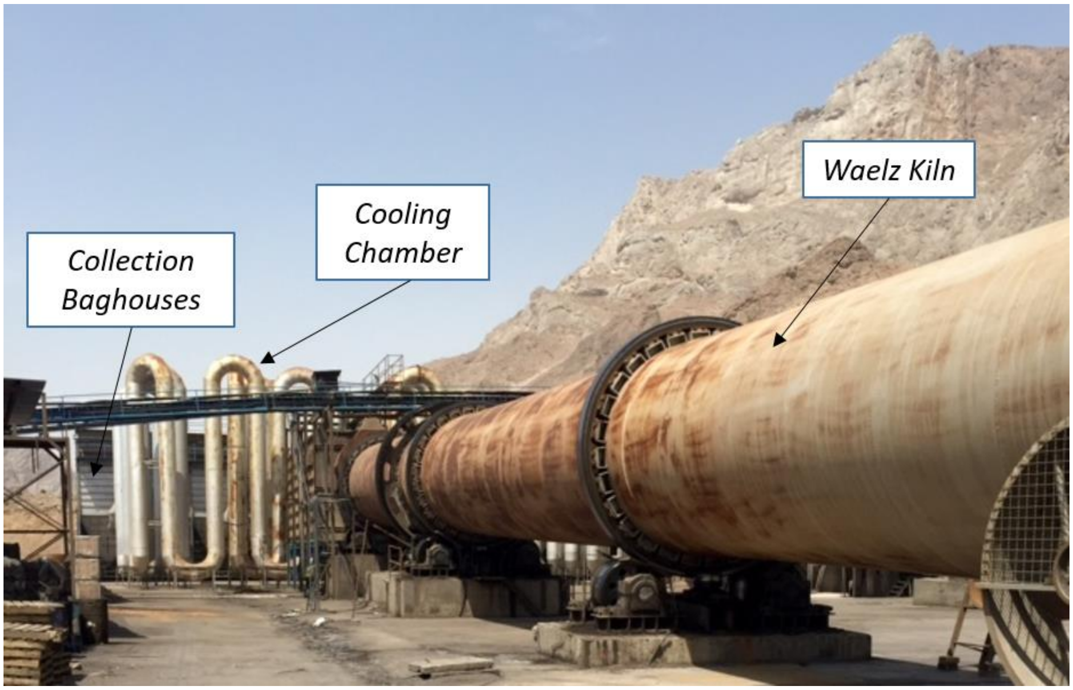
As mentioned before, many zinc operations make use of zinc's relatively high volatility to separate from other metals and minerals. As will be shown, vital to benefiting from this property of zinc is reducing it to elemental form, which is the function of the carbothermic reduction occurring within the Waelz kiln.

3. THE WAELZ KILN

A German invention first put in use in 1925, the Waelz kiln is a long and narrow, slowly rotating refractory-lined continuous kiln (see Figure 2). Zinc ore and a reductant (often a form of coal) are introduced into the kiln under flame to initiate the reaction. The kiln is kept under negative pressure via induced draft fans, which evacuate the air from the reaction chamber and promote the carbothermic reduction and subsequent volatization of zinc, simultaneous with the evolution of carbon monoxide. Kiln temperatures increase towards 1250 ºC via the natural heat evolved by the reaction (see Reaction 1 below). The induced draft fan carries the volatized zinc gas in a direction opposite to the flow of zinc-depleted solids (residue) towards the cooling chamber, where air is introduced. The air re-oxidizes and cools the zinc gas back to ZnO dust in solid form, now in a section of the kiln separate from the residue material, hence effectuating the separation process from the dilute source material. The carbon monoxide is similarly oxidized to form carbon dioxide (see Reaction 2). Water can also be introduced as a coolant. The ZnO dust is collected within the baghouse of the kiln before the exhaust gases are vented to the atmosphere and the ZnO dust recovered in concentrated form.

Typical product grades varying depending on mineral content but range between 50-85 % ZnO. Grade can be further improved by a second calcination at lower temperature to volatize impurities, reaching grades in the 90% range. Recoveries of Waelz kiln zinc processes can also approach 90%.

Figure 2: Isfahan Zinc Smelting, Iran –500 tpd ROM Waelz Kiln since 2007



Reaction 1: Separation via Reduction and Volatization

$$ZnO_{(in\ ore)} + C_{(coal)} = Zn_{(gas)} + CO_{(gas)}$$

Reaction 2: Recovery via Re-Oxidation, Cooling and Settling

$$Zn_{(gas)} + O_{2(g)} + CO_{(g)} = ZnO_{(s)} + CO_{2(g)}$$

4. CASE STUDY: ISFAHAN ZINC SMELTING, ISFAHAN, IRAN

Isfahan Zinc Smelting has been in operation since 1998, utilizing a variety of zinc recovery methods for the production of zinc concentrates and primary zinc metal. Since 2007, the Waelz kiln technology has been used to produce zinc oxide from the natural orebody of the area. 50% ZnO is produced from a low grade ore of 6% ZnO which was considered waste material before the installation of the kiln. Testwork and design was developed in association with Cinkom (formerly Cinkur) in Turkey, whose operations used Waelz kilns to upgrade 21% Zn ore into 60% ZnO starting in 1968.

Currently Isfahan is operating 4 Waelz kilns each processing up to 500 tons per day of run-of-mine mixed with 35 wt% Carbon anthracite (3:2 ratio) in 3.8 meter diameter by 60 meter long Waelz kilns (see Figure 2). A natural gas burner initiates the reaction at the front-end of the kiln, with the main energy supply coming from the anthracite. Residual zinc content in the discarded solids is 0.6 wt% Zn.

Figure 3: Isfahan Zinc Smelting, Iran –500 tpd ROM Waelz Kiln complete line

The total installed capital cost of the described Waelz kiln line as shown in Figure 2 and 3 is approximately $2,000,000 USD.

5. WAELZ KILN: STEEL INDUSTRY

5.1 Electric Arc Kiln Dust

Common to the recycled steel industry is to produce zinc oxide from electric arc kiln dust (EAFD) and recover zinc-free iron. Known are 20 Waelz kilns applications (average capacity 75,000 tpy, see Table 1) that process approximately 3,400,000 tpy of EAFD with typical feeds of 35 wt% ZnO.

Table 1. Known EAFD Waelz Kiln Applications Worldwide

Company	Year built	Capacity (tpy EAFD)
Horsehead – Palmerton, USA	1981	245,000 (3 kilns)
Horsehead – Calumet, USA	1988	72,000
Horsehead – Rockwood, USA	1990	200,000 (3 kilns)
Horsehead – Nucor, USA	2010	180,000 (2 kilns)
Steel Dust Recycling – Millport, USA	2008	120,000 (2 kilns)
Zinc Nacional – Monterey, Mexico	1982	150,000 (2 kilns)
Befesa Recytech – Noyelles-sous-Lenz, France	1993	83,000
Befesa – Freiburg,Germany	1991	100,000
Befesa – Duisburg, Germany	1992	105,000
Nuova Samia – Ponte Nossa, Italy		87,000
Ponte Vesme – Sardinia, Italy	1991	180,000 (2 kilns)
Aser – Bilbao, Spain	1987	100,000
Befesa – Metoks, Turkey	2008	60,000
Cinkur, Turkey	1980 (zinc ore)	200,000 (2 kilns)
Befesa – Chungbuk,South Korea	2012	100,000
Himeji – Himeji, Japan	1975	35,000
Sotetsu Metal – Alzu, Japan	1974	60,000
Sumitomo – Shisaka,Japan	1987	120,000 (2 kilns)
Taiwan Steel Union, Taiwan	1996	180,000 (2 kilns)

5.2 Direct Reduced Iron

Similar to EAFD applications several steel mill applications use volatization methods such as the Waelz kiln to remove zinc as an impurity from recyclable steel, producing direct reduced iron (DRI), making zinc oxide concentrate (short "HZO") in the process. See Table 2 for such known applications worldwide.

Table 2. Known DRI/HZO Waelz Kiln (or similar) Applications Worldwide

Location	Company	Supplier	Feed type	Feed tpa	Product(s)
South Korea, Chungbuk	ZincOx - Korea Zinc	"ZincOx"	EAFD	200,000	DRI, *HZO*
South Korea, Pohang	Posco	Nippon Steel Eng.	Iron Waste	180,000	DRI, *HZO*
South Korea, Gwangyang	Posco	Nippon Steel Eng.	Iron Waste	180,000	DRI, *HZO*
Japan, Hirohata	Nippon Steel	Midrex/Kobelco	Iron Waste	190,000	DRI, *HZO*
Thailand	Nakorn Thai Group	Inmetco	Iron ore fines	500,000	DRI
Italy, Piombino	Lucchini Steel	Inmetco/ Demag	Iron Waste	60,000	DRI, *HZO*
USA, Minesota	Erie Nugget	Midrex/Kobelco	Iron ore fines	500,000	PI
Taiwan	China Steel Corp.	Nippon Steel Eng.	Iron Waste	180,000	DRI, *HZO*
Japan, Hirohata	Nippon Steel	Midrex/ Kobelco	Iron Waste	190,000	DRI, *HZO*
Italy, Piombino	Lucchini Steel	Inmetco/ Demag	Iron Waste	60,000	DRI, *HZO*
Japan, Kimitsu	Nippon Steel	Nippon Steel Eng.	Iron Waste	180,000	DRI, *HZO*
USA, MI, Senatobia	Hartford Steel	Hartford Steel Technologies	EAFD	80,000	DRI, *HZO*
Japan, Hirohata	Nippon Steel	Midrex/ Kobelco	Iron Waste	190,000	DRI, *HZO*
USA, Indiana	Iron Dynamics	IDI	Iron ore fines	500,000	DRI
Japan, Kimitsu	Nippon Steel	Nippon Steel Eng.	Iron Waste	120,000	DRI, *HZO*
USA, Michigan	Rouge Steel	Maumee	Iron Waste	300,000	DRI, *HZO*
Thailand	Nakorn Thai Group	Inmetco	Iron ore fines	500,000	DRI
USA, Arkansas	Nucor Yamato	Allmet	EAFD	100,000	DRI, *HZO*

6. WAELZ KILN: ADVANTAGES AND DISADVANTAGES

Advantages

- Dry process; no water or drying requirements
- High tolerance for feed grade and compositional/mineralogical variability; effective at low zinc grades with high recoveries
- Comparatively low capital and operating cost
- Simple construction and operation; single step process
- No acid requirements and/or environmentally related treatments
- Easier management of dry waste product
- Comparatively high zinc recovery

Disadvantages

- Emissions treatment and control
- Source of reductant (coal) required
- Comparatively lower single pass product grade

7. REFERENCES

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