ME 216 – Engineering Materials II

Chapter 7

Production of Nonferrous Metals

Mechanical Engineering
University of Gaziantep

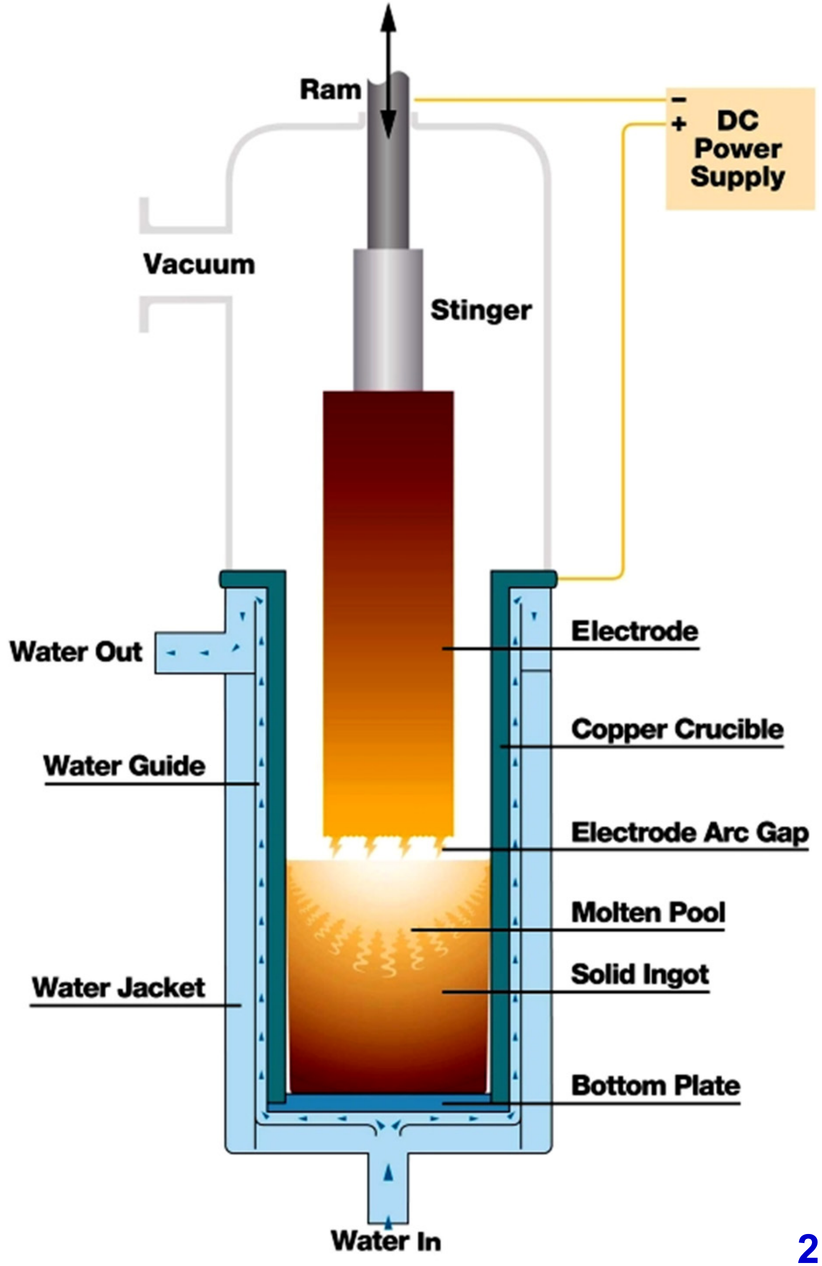
Prof. Dr. Ömer Eyercioğlu

- Even though ferrous metals and alloys are the most important and widely used engineering materials, nonferrous metals and alloys also find significance in engineering construction.
- They have a wide range of properties and uses for which ferrous alloys are not suitable.
- Most of the useful engineering alloys are made from two or more of the following metals, and various types and grades of these metals are obtained from refining processes:
  - **Aluminum (Al)**
  - **Copper (Cu)**
  - **Lead (Pb)**
  - **Magnesium (Mg)**
  - **Nickel (Ni)**
  - **Tin (Sn)**
  - **Zinc (Zn)**
- In general, nonferrous metals and alloys are more expensive than any iron or steel, but they hold their place in industry since they meet special requirements (e.g. **copper** is most useful due to its electrical properties, **aluminum** and **magnesium** are very light and provide very high strength/weight ratios, **tin** and **lead** have good corrosion resistance).

- Furnaces used for smelting nonferrous metals are different from those for iron and steel.

- **Blast furnace** (similar but smaller than those for iron smelting) is used for reducing oxide ores of nonferrous metals (e.g. **copper**, **tin**, **lead**, **zinc**). Some ores contain sulphides which are decomposed in **roasting ovens** to drive off sulphur and leave the oxide. **Reverberatory furnace** (similar to open-hearth furnace) is often used to smelt nonferrous metals.

- **Vacuum arc furnace** (consumable electrode unit) is a special type of electric furnace. It is used for melting various metals (such as **high purity steels**, **titanium**, **zirconium**). The metal used to charge the furnace is fashioned into long rods by briquetting and welding into electrode. Vacuum in furnace is constantly maintained to remove gases before being absorbed by metal. By this method of melting in water-cooled mold at the base of furnace, a solid ingot is gradually formed.



PRODUCTION OF ALUMINUM

Bauxite (about 4 kg)
- **Gibbsite (Al_2O_2. H_2O)**
- **Diaspore (Al_2O_3. H_2O)**

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Bayer Process
(ore-dressing & calcination)

↓

Alumina: 99.4% Al
(about 2 kg)

↓

Hall-Heroult Process
(reduction by electrolysis)

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Electrolytic Al: 99.6% Al
(about 1 kg)

↓

Hoopes Process
(three-layer electrolytic cell)

↓

Pure Al: 99.99% Al

BAYER PROCESS

1. MIXING
- Crushing & grinding **bauxite ore**.
- Mixing with **caustic soda**, **lime**, **sodium hydroxite**, and **hot water**.

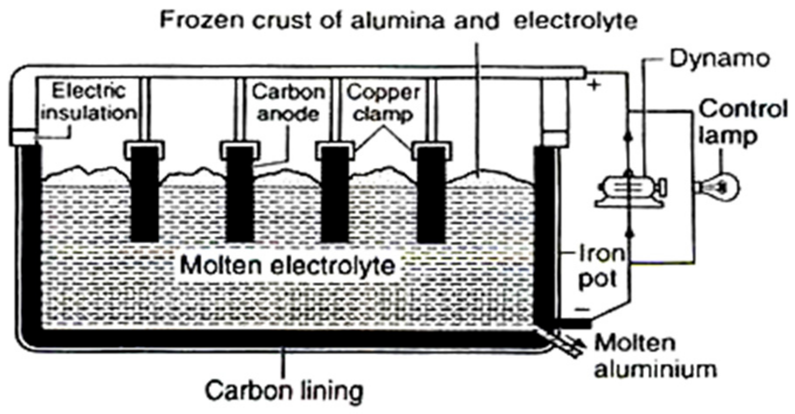
2. DIGESTION
- Under high pressure & heat, **caustic soda** dissolves **alumina** in bauxite to form **sodium aluminate**.

3. CLARIFICATION
- **Sodium aluminate** remains liquid.
- Iron oxides and other solid impurities are pumped to disposal as **red mud**.

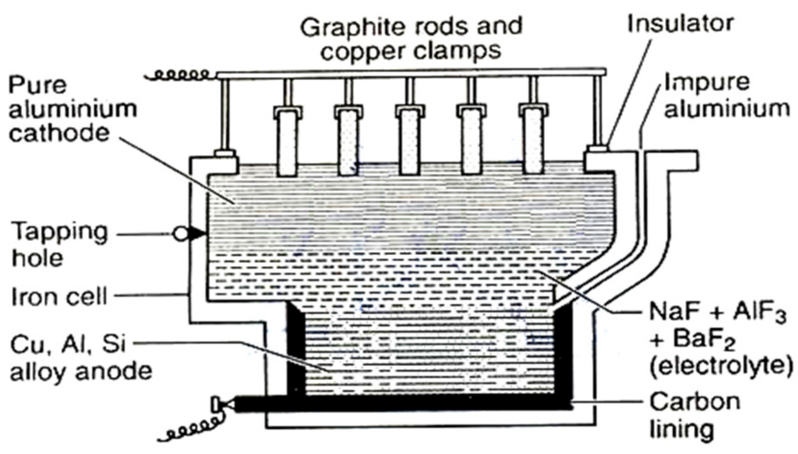
4. PRECIPITATION
- **Sodium aluminate** is seeded with **aluminum hydroxite**, and converted to **aluminum hydrate**.
- As cooling continues, **aluminum hydrate** settles to bottom while **sodium hydroxite** rises to top.

5. CALCINATION
- **Aluminum hydrate** is calcinated (roasted) at 1100 °C to remove water, and **pure alumina (99.4%)** is obtained.

HALL-HEROULT PROCESS



HOOPES PROCESS



Facts and Properties:

- ✪ White or grey-white metal
- ✪ Melting point of 660 °C
- ✪ Very ductile & malleable
- ✪ Better strength-to-weight ratio than steel
- ✪ Good thermal & electrical conductivity

PRODUCTION OF COPPER

Sulphide Ores

- Chalcocite (Cu_2S): 79.8% Cu
- Chalcopyrite ($CuFeS_2$): 34.5% Cu

↓

Ore-Dressing

- Crushing in jaw crushers
- Grinding in ball mills
- Concentrating by froth floatation

↓

Concentrated Cu

↓

Smelting in Reverbatory Furnace

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Matte Cu: 40-45% Cu

↓

Converting in Bessemer Converter

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Blister Cu: 98% Cu

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Refining (Poling) in Reverbatory Furnace

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Tough-pitch Cu: 99% Cu

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Electrolysis to deposit Cu on cathodes

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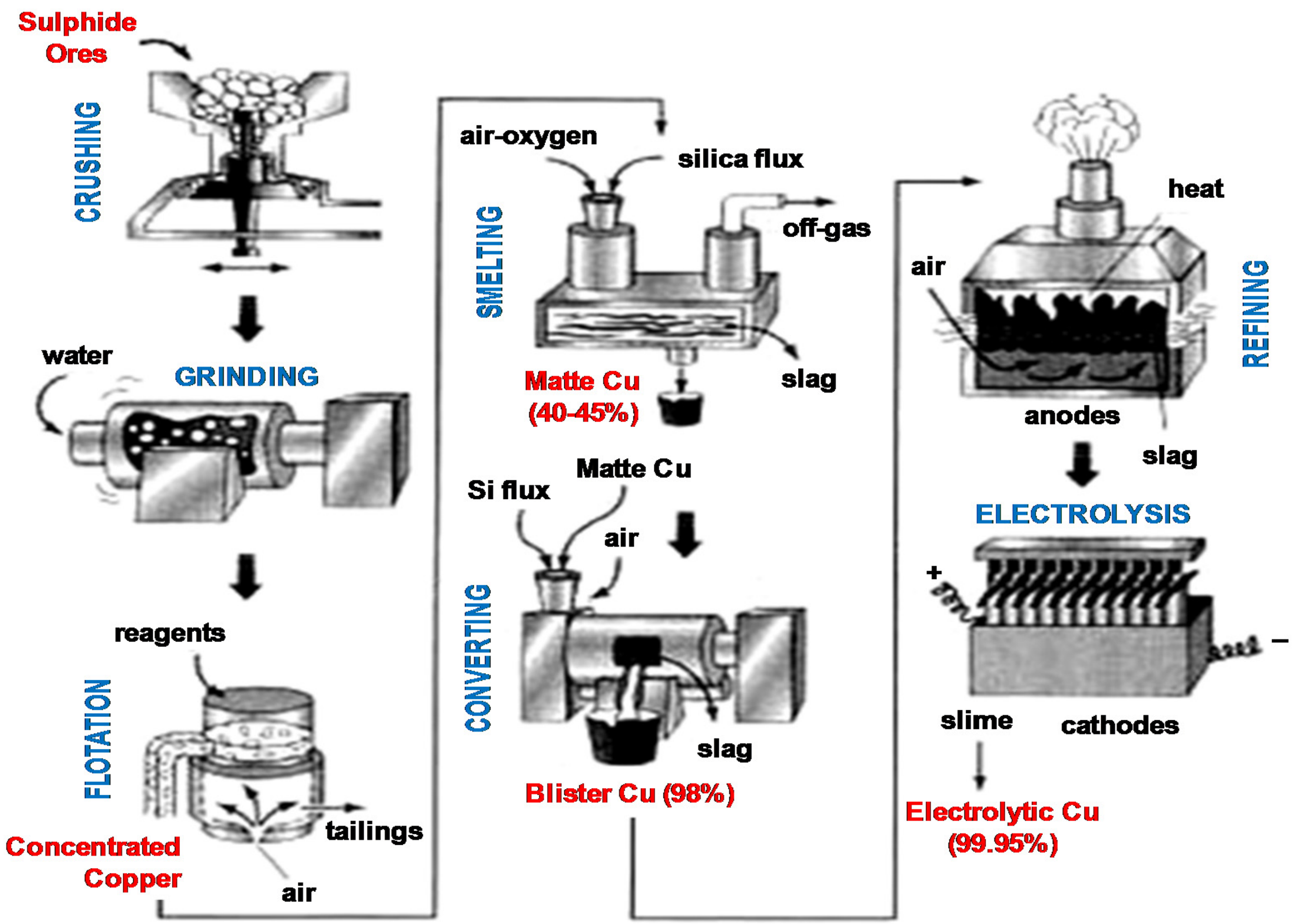
Electrolytic Cu: 99.95% Cu →



Further refining by melting under protective atmosphere to remove residual oxygen (0.03-0.06%)

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Oxygen-Free High-Conductivity (OFHC) Copper

Facts and Properties:

- ✪ Soft, heavy, reddish metal
- ✪ Melting point of 1083 °C
- ✪ High ductility
- ✪ Excellent thermal & electrical conductivity

PRODUCTION OF LEAD

Galena (PbS): 1-10% Pb

↓

Concentrating by floatation

↓

Roasting with O_2 (at 600-700 °C)

$$2PbS + 3O_2 \rightarrow 2PbO + 2SO_2$$

↓

Smelting with coke (in blast furnace at 900 °C)

$$2PbO + C \rightarrow 2Pb + CO_2$$

↓

Crude Pb: 60-80% Pb

↓

Refining by heating (in air at 400 °C)

↓

Removing impurities

- Cu (by adding sulphur)
- Sb & As (by selective oxidation)
- Zn (by distillation)
- Ag (by electrolysis)

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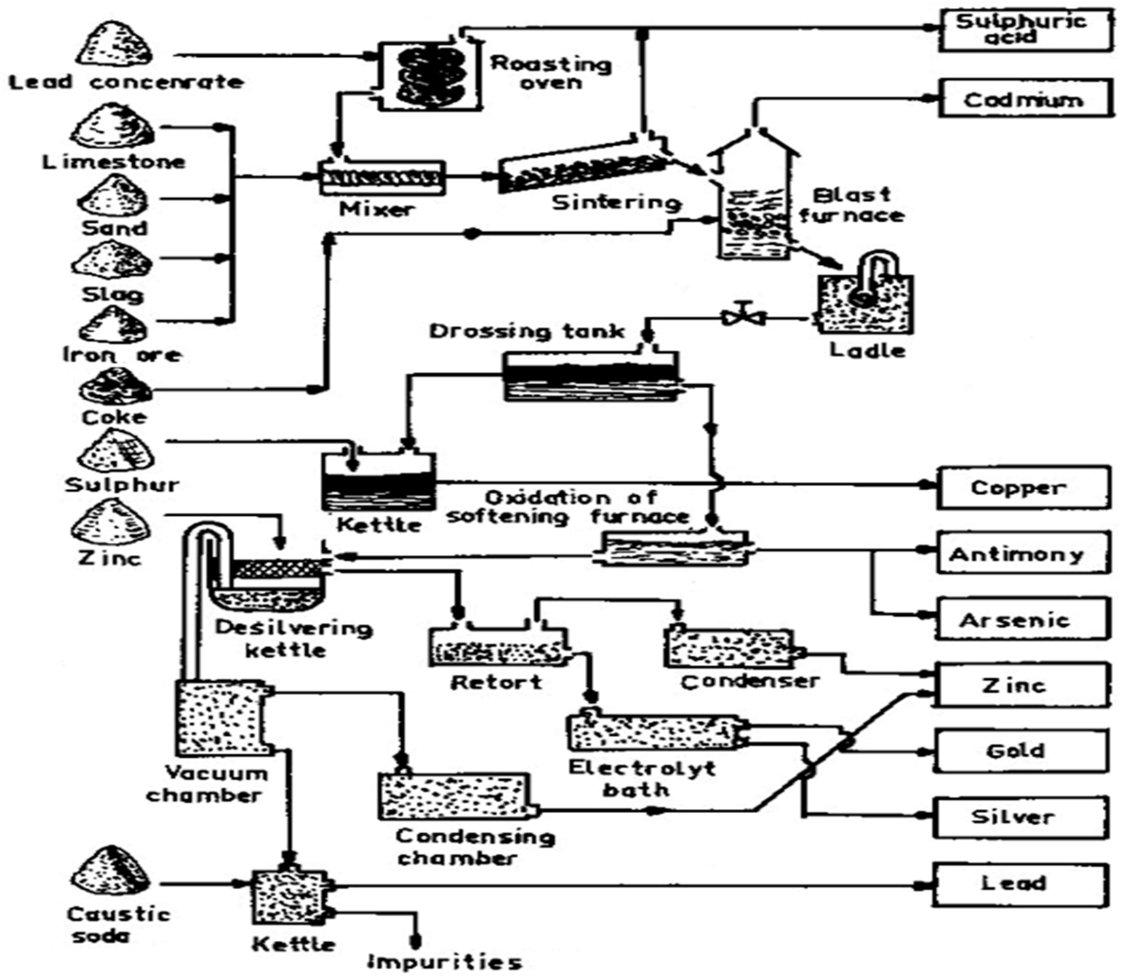
Pure Pb: 99.9% Pb



Facts and Properties:

- ✪ Heavy, greyish metal
- ✪ Melting point of 327 °C
- ✪ High malleability, low strength
- ✪ Good corrosion resistance

PRODUCTION OF MAGNESIUM

Seawater: 1300 ppm Mg

↓

Mixing with milk of lime

↓

Magnesium Hydrate

↓

Adding hydrogen chloride (HCl)

↓

Magnesium Chloride (MgCl)

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Electrolysis with carbon anodes & steel cathodes using 60,000 A in an electrolyte (Ca + NaCl)

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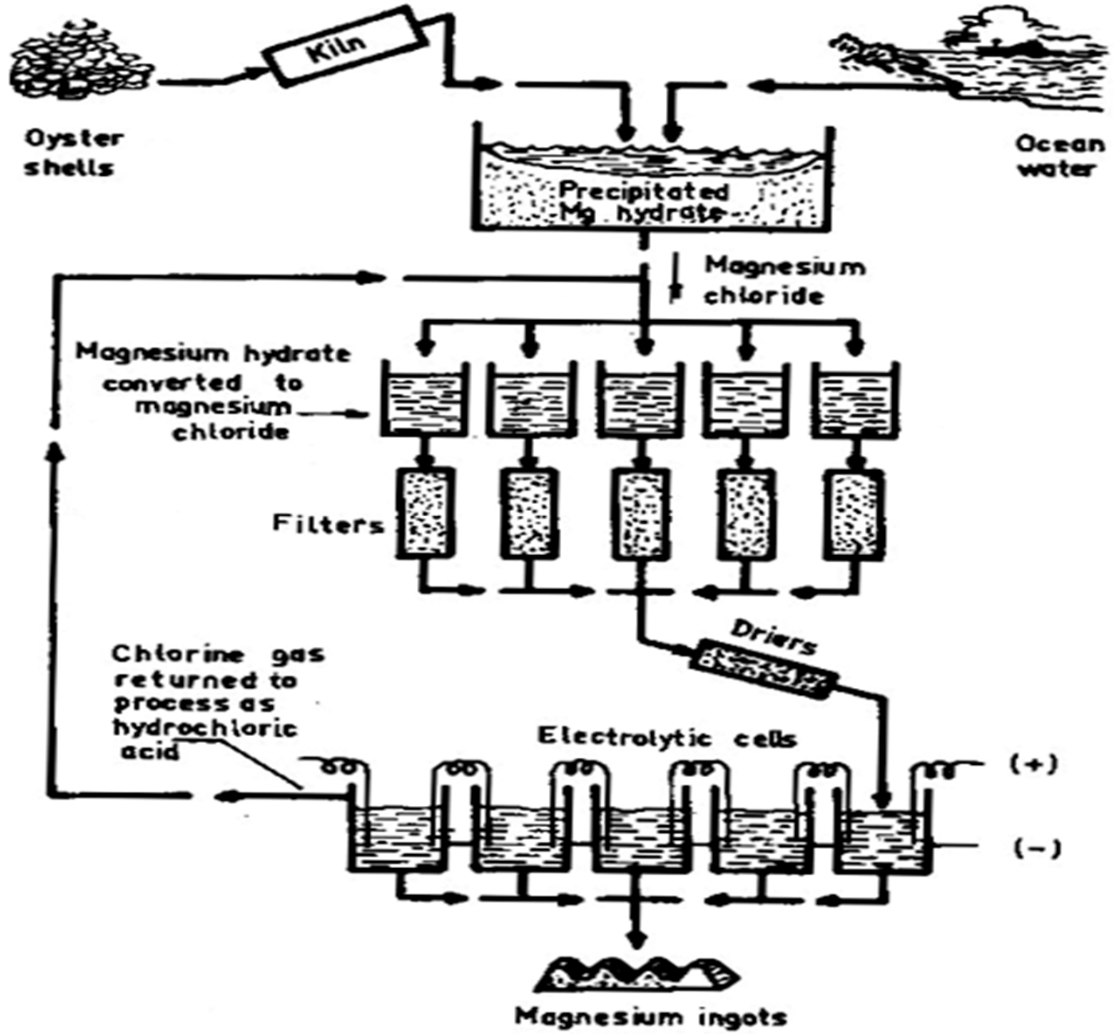
Pure Mg (deposited on cathodes)



Facts and Properties:

- ✪ Light, soft, silver-white metal
- ✪ Melting point of 650 °C
- ✪ Chemically active metal

PRODUCTION OF NICKEL

Penthandite [NiS.(FeS)$_2$]

↓

Concentrating by floatation

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Smelting in furnace

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Matte Ni
(having Cu & iron sulphides)

↓

Refining by Mond Process:

- **Crushed & heated to drive off sulphur**
- **Converted to NiO**
- **Treated with sulphuric acid to remove Cu**
- **Reduced with water gas (H + CO) at 300 °C**

↓

Pure Ni: 99.8% Ni

Facts and Properties:

- ✪ Whitish metal
- ✪ Melting point of 1452 °C
- ✪ Low strength
- ✪ Resistance to corrosion & oxidation

PRODUCTION OF TIN

Cassiterite (SnO_2): tin stone (1-5% Sn)

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Washing to remove impurities

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Heavy tin oxide

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Smelting in reverbatory furnace
(with powdered coal & lime at 1200 °C)

↓

Matte Sn

↓

Refining in two stages:

- **Liquation (at low temp.) to remove Cu, Fe, As**
- **Oxidation in open crucible (kettle) to remove Zn**

↓

Pure Sn: 99% Sn

↓

Further refining by electrolysis

↓

Pure Sn: 99.9% Sn

Facts and Properties:

- ✪ White coloured metal
- ✪ High malleability, low strength
- ✪ Melting point of 232 °C
- ✪ Good corrosion resistance

PRODUCTION OF ZINC

Sphalerite (ZnS): zincblende, ruby jack

↓

Floatation to remove Pb, Cu, iron sulphides

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Concentrated Zinc

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Roasting Roasting with O_2

↓

Zinc Oxide

↓

Purifying in two ways →

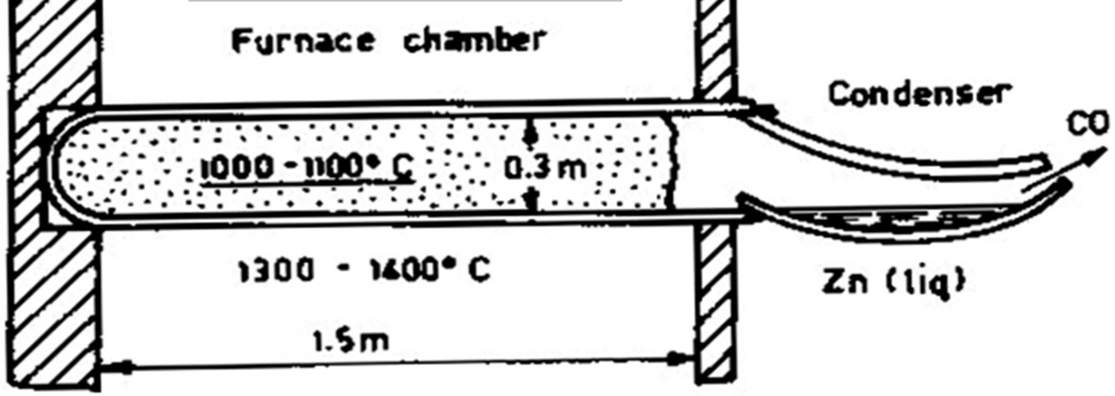
Distillation in Zinc Retort:

- **Zinc oxide** (with coke) is pressed into walls of briquettes, and retorts are placed in furnace at 1200-1400 °C.
- Due to the reaction occurring in furnace at atmospheric pressure, **Pure Zn** is produced in vapour form and then condensed at 500 °C.

Roasting & Electrolysis

- **Zinc concentrate** is roasted & leached (i.e. soluble particles are removed) with a weak solution of **sulphuric acid**.
- Other metals are filtered out and **the solution (zinc sulphate)** is pumped into electrolytic tanks.
- **Cathodes (pure Al)** and **anodes (Pb-Ag alloy)** are lowered into tanks, electric current is passed through solution, and **Pure Zn** is deposited.

$$ZnO + C \rightarrow Zn + CO$$



Facts and Properties:

- ✪ Bluish-white metal
- ✪ Melting point of 419 °C
- ✪ Low strength, low ductility
- ✪ Easily formable & machinable
- ✪ Readily attacked by alkalis and acids

- Conventional crucible (melting) methods are **not possible at high temperatures** needed to produce these metals as liquids. Thereby, they are **reduced directly to powder form**. Later, metallic powder is **consolidated by sintering** in solid state.

- Melting points of refractory metals and their processing are given below:

  - **Tunsgten (W, 3410 °C)** and **Molybdenum (Mo, 2610 °C)** are reduced from their oxides of **scheelite ($CaWO_2$)** and **molybdenite (MoS_2)**, respectively. In both cases, first stage is to prepare **pure oxide powder** by chemical treatments. Then, it is reduced to metal by heating in a stream of **hydrogen gas**, which is an effective reducing agent for these metals. Such treatment gives a clean metal, and there is no problem of carbide formation.

  - **Niobium (Nb, 2470 °C)** and **Tantalum (Ta, 2980 °C)** are more reactive metals, and hence **their fluorides** are usually reduced with **sodium**.

  - **Rhenium (Re, 3170 °C)** is obtained as by-product of extraction and refinement of **Mo & Cu**.

  - **Osmium (Os, 3000 °C)**, being the heaviest known metal, is found as a trace element in alloys (**mostly in platinum ores**).