



INTRODUCTION TO METALLURGY

Metallurgy: Science and technology of extracting metals from their ores and of compounding alloys.

BRANCHES OF METALLURGY

- Physical Metallurgy (Physical Properties of Metals) studies metals and metal alloy systems, atomic structure, equilibrium and phase diagrams, stress etc.
- Mechanical metallurgy (Mechanical Properties of Metals) deals with stress-strain relationship, fatigue, mechanism, elasticity, plasticity, pressure shaping of metals etc.
- Foundry Engineering- moulding and casting of metals and non-metals into dimensions, shapes and size.



- Heat technology includes heat treatment of metals to gain physico-chemical properties that cannot be obtained directly from furnaces.
- Extractive Metallurgy entails production and processing of various metals; it studies chemical and thermodynamics principles involved (Chemical Metallurgy)

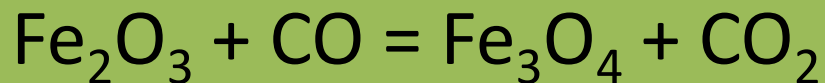
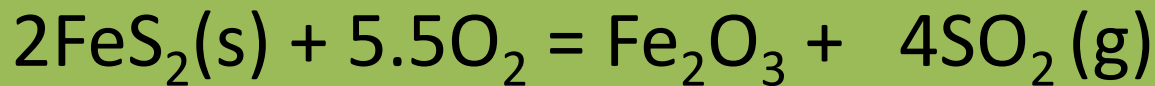
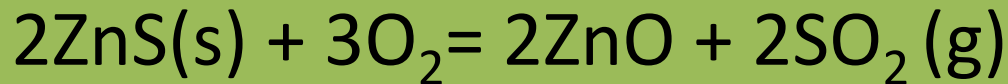


CLASSIFICATION OF EXTRACTIVE METALLURGY

It is almost impossible to follow consistently any pattern of classification, but three major types of classification could be considered according to:

PHASES INVOLVED

- **Gas-Solid** Examples; Roasting, Gas reduction. Roasting of sulphides to form the oxides and sulphur dioxide.



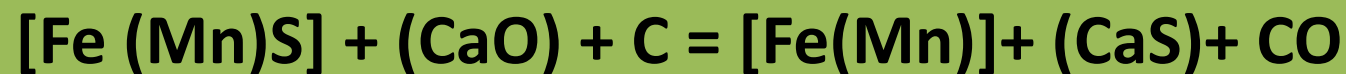
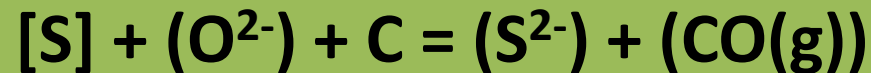
Pyrite by product called pyrite sinter



B. Gas-Liquid Example: Bessemer blowing, distillation. The blowing of air through the molten iron-copper matte with simultaneous addition of silica in the Bessemer converter.



C. Liquid – Liquid Example: slag-metals reactions. Desulphurization of liquid steel by means of a basic slag given by the reaction.



Blast furnace Operation



D. Solid–liquid e.g. Liquefaction Leaching and precipitation separation of iron from tin, keeping the impure tin at temperature above its melting point, the compound FeSn_2 will separate out as a solid phase, leaving behind a liquid with less than 0.01% Fe Liquefaction- the draining of almost pure liquid at an inclined angle.



Most metals are found in nature in solid inorganic compounds (minerals) except Au and Pt, Pd, Rh, Ru, Ir, Os. N.B source of minerals \rightarrow oxides (O^{2-}), sulphides (S^{2-}) and carbonates (CO_3^{2-}). Silicates are abundant, BUT they are generally difficult to treat (not economically viable)



TYPE	MINERALS
Uncombined metals	Ag, Au, Bi, Cu, Pd, Pt
Carbonates	BaCO ₃ (witherite), CaCO ₃ (calcite, limestone), MgCO ₃ (magnesite), CaCO ₃ · MgCO ₃ (dolomite), PbCO ₃ (cerussite), ZnCO ₃ (smithsonite)
Halides	CaF ₂ (fluorite), NaCl (halite), KCl (sylvite), Na ₃ AlF ₆ (cryolite)
Oxides	Al ₂ O ₃ · 2H ₂ O (bauxite), Al ₂ O ₃ (corundum), Fe ₂ O ₃ (hematite), Fe ₃ O ₄ (magnetite), Cu ₂ O (cuprite), MnO ₂ (pyrolusite), SnO ₂ (cassiterite), TiO ₂ (rutile), ZnO (zincite)
Phosphates	Ca ₃ (PO ₄) ₂ (phosphate rock), Ca ₅ (PO ₄) ₃ OH (hydroxyapatite)
Silicates	Be ₃ Al ₂ Si ₆ O ₁₈ (beryl), ZrSiO ₄ (zircon), NaAlSi ₃ O ₈ (albite), Mg ₃ (Si ₄ O ₁₀)(OH) ₂ (talc)
Sulfides	Ag ₂ S (argentite), CdS (greenockite), Cu ₂ S (chalcocite), FeS ₂ (pyrite), HgS (cinnabar), PbS (galena), ZnS (sphalerite)
Sulfates	BaSO ₄ (barite), CaSO ₄ (anhydrite), PbSO ₄ (anglesite), SrSO ₄ (celestite), MgSO ₄ · 7H ₂ O (epsomite)



What is involved?

- Mining (then crushing and grinding)
- Concentrating the ore → remove the gangue
- e.g. magnetic separation, flotation, amalgamation
- Reducing the concentrate to obtain free metal
- Refining/purifying the metal
- Alloying → mixing metal with other elements to modify properties



Pyrometallurgy

Use high temperatures to alter the mineral chemically and reduce it to the free metal. It requires large amounts of energy and often the source of atmospheric pollution. Used in concentration, reduction and refining processes.

Some pyrometallurgical processes include; Calcination:→ Heat ore to decompose and eliminate volatile products. Carbonates are often calcined to drive off CO₂ and form metal oxide e.g.



Require temps ~400-500°C (1000°C for CaCO₃)

Hydrated minerals lose H₂O at ~100-300°C



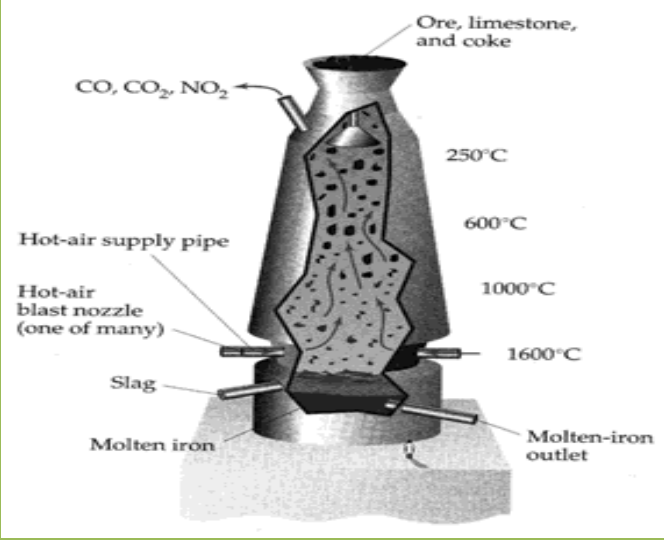
- Roasting: → Thermal treatment causes chemical reaction between ore and furnace atmosphere.
 - Leads to reduction or oxidation (depending on atm) and may be accompanied by calcination .e.g. Roasting of sulphides to produce oxides
- $2\text{ZnS}(s) + 3\text{O}_2(g) \rightarrow 2\text{ZnO}(s) + 2\text{SO}_2(g)$ e.g. Sulphides of less active metals can be roasted to the free metal; $\text{HgS}(s) + 3\text{O}_2(g) \rightarrow \text{Hg}(g) + \text{SO}_2(g)$
 - e.g. Free metal also obtained by using reducing atm: $\text{PbO}(s) + \text{CO}(g) \rightarrow \text{Pb}(l) + \text{CO}_2(g)$
- Smelting: → Melting process in which material separates into 2 or more layers in a chemical reaction. → Form molten metal + slag



- Slag forms when basic metal oxide reacts at high temp's with molten silica (SiO_2) e.g. $\text{CaO(l)} + \text{SiO}_2(\text{l}) \rightarrow \text{CaSiO}_3(\text{l})$ Slag = mainly molten silicate minerals (with aluminates, phosphates, fluorides and other inorganic compounds)
- Refining: \rightarrow Treatment of crude, relatively impure metal product to improve purity. \rightarrow Produce pure metal or mixture of well-defined composition.
- PYROMETALLURGY OF IRON: Source: iron oxide minerals e.g. hematite = Fe_2O_3 , magnetite = Fe_3O_4

Reduction of iron oxides \rightarrow in blast furnace

- Charged at the top with mixture of: iron ore + coke + limestone



Coke = coal heated in absence of air to drive off volatiles; = 85-90% C; Fuel → produces heat as it is burned in lower part of furnace Also, source of reducing gases → CO + H₂
 Limestone = CaCO₃; Source of basic oxide in slag formation; Hot air blown in from bottom of furnace for combustion of coke.

Reactions in furnace: Combustion of coke: $2C(s) + O_2(g) \rightarrow 2CO \Delta H = -221 \text{ kJ}$;

Water vapour also reacts with coke: $2C(s) + H_2O(g) \rightarrow CO + 2H_2 \Delta H = +131 \text{ kJ}$

Limestone is calcined in upper part of furnace: $CaCO_3(s) \rightarrow CaO(s) + CO_2$;

Iron oxides reduced by CO and H₂ in upper part of furnace:



e.g. $\text{Fe}_3\text{O}_4(\text{s}) + 4\text{CO}(\text{g}) \rightarrow 3\text{Fe}(\text{s}) + 4\text{CO}_2(\text{g}); \Delta\text{H} = -15 \text{ kJ}$

$\text{Fe}_3\text{O}_4(\text{s}) + 4\text{H}_2(\text{g}) \rightarrow 3\text{Fe}(\text{s}) + 4\text{H}_2\text{O}(\text{g}); \Delta\text{H} = +150 \text{ kJ.}$

Reduction of other elements also occurs in hottest part of furnace where C is the major reducing agent. Molten iron collects at bottom of furnace with a layer of slag on top. Tap furnace periodically to remove iron(also drain off slag). Tapped iron is NOT PURE contains Si, Mn, P, S, C.

Formation of steel:

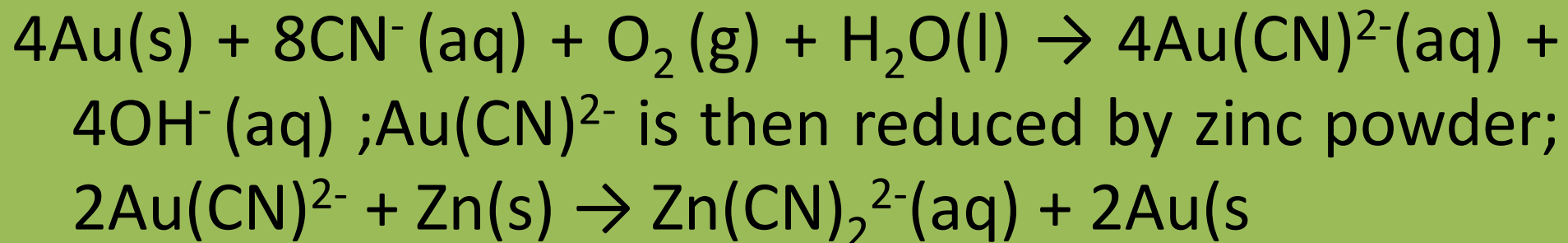
Remove impurities by oxidation in a converter; use O_2 or $\text{O}_2 + \text{Ar}$ as oxidising agent; C & S expelled as CO and SO_2 gases. Si oxidised to SiO_2 and adds to slag.

Presence of basic slag NB for P removal: $3\text{CaO}(\text{l}) + \text{P}_2\text{O}_5(\text{l}) \rightarrow \text{Ca}_3(\text{PO}_4)_2(\text{l});$ Monitor O_2 coming off to see when reaction is complete.



Hydrometallurgy

Leaching: Desired metal containing compound is selectively dissolved. Leaching agents used: H_2O or aqueous soln's of acid/base/salt \rightarrow Often form a complex ion. e.g. Gold concentrated by the process of cyanidation; Leaching agent = NaCN soln in presence of air





Electrolysis of molten salt or aqueous solution.

- e.g. Na, Mg, Al; H_2O more easily reduced than metal ion.

Electrorefining of Copper to obtain pure Cu

Anodes = large slabs of crude Cu; Cathodes = thin sheets of pure Cu; Electrolyte = acid soln of $CuSO_4$; Apply voltage \rightarrow get oxidation of Cu at anode and reduction of Cu^{2+} at cathode; Oxid. & reduct. more readily than that for H_2O .

Impurities in anode includes: Zn, Ni, As, Se, Te, precious metals incl. Au & Ag

Metallic impurities that are more active than Cu are also readily oxidised at the anode, but do not plate at the cathode because their reduction potentials are more negative than that for Cu^{2+} . Less active metals are not oxidised at the anode \rightarrow collect as sludge below the anode



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