Lecture 1: introduction

Contents

Key words: Life cycle assessment, metal extraction, energy resources.

Preamble

Materials and heat balance of metal extraction processes constitute a very important exercise to know the flow of materials and energy and to identify the amount of wastes produced and energy consumed. Productions of metals from natural reserves are associated with waste production and energy consumption.

In the future the consumption of metals is bound to increase particularly in India in order to improve its infrastructure and standard of living of its people. An assessment of metal production processes is called for in order to optimize the material and energy consumption to conserve the natural resources of metals and energy. The present course on materials and heat balance is developed to keep in mind the energy and environment issues related to metal extraction processes.

For this purpose several problems are discussed and the results are analyzed. The fundamentals of extraction processes are discussed to the extent of their utility in problem solving. Reader may go through the references given for the detailed description.

Characterization of natural reserves of metals

The natural reserve of a metal is called “ore”. Ore is an aggregate of minerals. A mineral in an inorganic compound in which elements are mixed in stoichiometric proportion, for example Al_2O_3 is a mineral in which 2 moles of aluminum are combined with 1.5 moles of oxygen. An ore of any metal contains valuable mineral and gangue minerals. Valuable mineral is the mineral which is used to produce metal.

In the ore, metal grade is important.

Metal grade of an ore = $\frac{\text{Amount of metal in ore}}{\text{Amount of ore.}} \times 100$

It must be noted very clearly that ore does not contain metal but metal in the ore is in the form of a mineral. Metal grade is used to characterize an ore reserve. For example metal grade of iron in pure Fe_2O_3 is 70%. IF iron ore contains 80% Fe_2O_3, then iron grade of ore in 56%. This means that 44% of the ore is waste both in terms of solid and oxygen of the valuable mineral. In the following table metal grade of certain ores, valuable minerals etc. are given:

Metal	Ore	Valuable mineral	Metal grade (%)
AL	Bauxite	$Al_2 O_3$	17.4%.
Ti	Ilmenite	$Ti O_2$	36%
C4	Sulphide	$Cu Fe S_2$	2 to 3%.
Fe	Hematite	$Fe_2 O_3$	56% 64%
Ni	Sulphide ore	$Ni_3 S_2$	2.3%
Pb	Sulphide ore	PbS	5.5%

We note the following form the above table:

1) Metal in the valuable mineral is chemically combined with either oxygen or sulphur.
2) Metal grade in sulphide ore is very low as compared with oxide ores.
3) Low grade of any ore means large production of wastage. Thus waste production is a part of metal production from natural reserves.

Metal extraction requirement:

The chemical combination of metal with sulphur or oxygen in a mineral is accompanied with high heat of formation

Mineral	Heat of formation $-\Delta H_f^o$ (k cal /kg mole)
Fe_2O_3	198 x10^3
Al_2O_3	380 x10^3
Cu_2s	19 x10^3
Zns	44 x10^3
Pbs	22 x10^3
Fe_3O_4	26 x10^3
$Ti O_2$	218 x10^3
MgO	142 x10^3

Thus large amount of energy would be required for example to produce Fe or Al from their respective minerals. Two basic methods of metal extraction are:

Pyrometallurgical extraction

This method depends on whether oxide ore or sulphide ore is employed for metal extraction. In the extraction first step is to upgrade the metal grade by employing mineral beneficiation technologies. The concentrate is then mixed with a suitable reducing agent and the mixture is followed by smelting to separate gangue minerals form metal. Here large amount of energy is required to facilitate separation of metal from gangue.

Energy source and its consumption are important. For the sulphide ore the following route is employed.

Sulphide is first converted to oxide and then following by smelting. Zinc and lead are produced by this route.

In another route sulphides are used to obtain by matte by matte smelting. It is used to produce copper.

Hydrometallurgical extraction

Hydrometallurgical extraction is mainly suited got lean ores.In the hydrometallurgical extraction metal is brought in to solution by leaching, which is then followed either by hydrogen reduction or electrolytic reduction to obtain metal.

This route is used to produce Al and Mg.

Energy requirement for metal production

Pyrometallurgical extraction of metals requires large amount of energy as shown in the following table: (The following values are approximates and the exact value can be seen in reference given at the end of this lecture)

Metal	Gross energy Requirement (mj/kg metal)
Titanium	360
Aluminium	220
Nickel	110
Zinc	50
copper	40-50
Steel	15-20

Metal grade of the ore is important. Low grade ore will consume more energy. Additional energy is required for mining and mineral processing to remove gangue mineral.

This is particularly true for copper and nickel extraction: for example 0.5% Cu grade of ore will consume 250 Mj/kg of energy which will decreases to 50 MJ/kg when copper grade of ore is 2%. Similarly a nickel grade of 0.5% will require 375 MJ/ kg energy which will decrease to 150 MJ / kg when nickel grade is 2%. Metal grade of ore is very important.

Source of energy

In pyrometallurgical extraction thermal energy is required. Fossil fuel is the source of energy. Fossil fuels are the non renewable source of energy and hence their optimum utilization is important. Further thermal energy from fossil fuel is derived by combustion which leads to production of products of combustion like CO, CO_2, NO_x etc. Large energy requirement demands higher consumption of fossil fuel.

Thus optimum utilization of fossil fuel in pyrometallurgical extraction is important from the point of view of conservation of natural resources and cleanliness of the environment.

Environmental issues

The production of metals from natural reserves results in the formation of emissions, unwanted solids, liquids and gases like CO, CO_2, NO_x SO_2, SO_3 etc directly (during mining and processing) and indirectly(associated with the consumption of raw materials and utilities, for example in the generation of electric power. In the supply chains of metal needs, mineral resource extraction and processing are particularly critical stages for the potential release of gas, liquid and solid emissions.

Environment impact of the process depends on metal grade of ore, electrical energy source, fuel types and material transport as well as processing technology. As higher grade ore reserves of metal decrease, there will be a dramatic effect on the energy consumption and accompanying greenhouse emissions from metal production processes.

The environment impacts for cradle-to-gate metal production (cradle-to-gate is an assessment of a partial production life cycle from resource extraction to the factory gate) are given in the following table:

Environmental impacts for “cradle-to-gate” metal production

Metal	process	GER * (MJ/kg)	GWP$ (kg CO_{2e} / kg)	AP# (kg SO_{2e}/kg)	SWB## (kg/kg)
Nickel	flash furnace smelting and sherritt Gordon refining	114	11.4	0.130	65
	pressure acid leaching Sx/Ew	194	16.1	-	351
Copper	Smelting /converting and electro –refining	33	3.3	0.040	64
	Heap leaching and Sx/Ew	64	6.2	-	125
Lead	Lead blast furnace	20	2.1	0.022	14.8
	Imperial smelting process	32	3.2	0.035	15.9
Zinc	Electrolytic process	48	4.6	0.055	29.3
	Imperial smelting process	36	3.3	0.036	15.4
Aluminum	Bayer refining ,Hall- Heroult smelting	211	22.4	0.131	4.5
Titanium	Beecher and Kroll process	361	35.7	0.230	16.9
Steel	Integrated route (BF and BOF)	23	2.3	0.020	2.4
Stainless steel	Electric furnace and Argon –Oxygen decarburization	75	6.8	0.051	6.4

* GER: Gross energy requirement

$ GWP: Global warming potential.

AP: Acidification potential.

SWB: solid waste burden.

Course objective

The aim of the course is to develop a quantitative feel about the energy requirement and waste production to extract metal form ore.

To meet the above objectives the lectures emphasize on the materials and energy balance calculations in metal extraction processes. The concepts will be given in brief and to the extent that would be required to solve the problem.

Regarding the organization of the course, first few lectures are on the basics of materials and energy balance like unit and dimensions, stoichiometry, thermo- chemistry. Remaining lectures cover the material and energy balance in different unit processes employed for metal production.

Some lectures are also included to address the energy balance in gasification and in high temperature industrial furnaces.

References

1) TE Norgate**,** S. jahaushahi and W. J Rankins:
   Assessing the environmental impact of metal production processes; available on line in goggle
2) H.S. Ray: industrial and scientific aspects of non-ferrous metals production , Available on line in goggle