ME 216 – Engineering Materials II

Chapter 5

Extractive Metallurgy

Mechanical Engineering
University of Gaziantep

Prof. Dr. Ömer Eyercioğlu

- **Extractive metallurgy** is the science of converting ores to pure metals. It begins with procurement of ores from mines, and culminates in the form of pure metal through various processes.
- The ores are generally concentrated after mining through **ore-dressing**, in which they are processed to appropriate size & shape and agglomerated to reduce losses in transportation.
- The concentrated ore is put through **extraction processes** involving chemical reactions for releasing the pure metal from rest of the impurities, and finally pure metal is collected separately.

ORE-DRESSING (physical processes)

- **Crushing & Grinding**
- **Sizing & Sorting**
  - Screening
  - Sorting
    - *Classification*
    - *Floatation*
    - *Magnetic Separation*
- **Agglomeration**
  - Pelletizing
  - Sintering
  - Nodularizing

ORE

↓

Extractive Metallurgy

↓

PURE METAL

EXTRACTION (chemical processes)

- **Calcination**
- **Roasting**
- **Smelting**
- **Electrolysis**
- **Fire Refining**
- **Distillation**

Metal Ores (Metal Cevherleri)

- Almost all metals (except for magnesium and plutonium) are derived from ores that are concentrations of appropriate minerals situated at or near the earth's crust.
- Ores contain various important engineering metals as parts of chemical compounds. They are removed from the earth crust (mined) by a method appropriate to the size of ore deposit, its shape and depth below the surface of earth.
- In general, the ores contain the valuable mineral in **a banded array** (i.e. the valuable mineral being sandwiched between bands of other minerals).
- Chemically, an ore may contain three groups of minerals:

  1. The valuable mineral

  2. Compounds of this mineral (may be of secondary valuable)

  3. Useless gangue material (not valuable)

- Native metal rarely occurs in nature as pure substance, but is found **as a compound**.
- The most common ore compounds are **oxides**, **oxy salts**, **sulphides**. Oxide ores are often result of oxidation of sulphides, only few oxides (e.g. Fe_3O_4) occur as primary oxide deposits.
- The minerals in this class often associate in families (e.g. zinc and lead are always found together, lead is seldom found without silver, and so on).

- **Ore-dressing** is the preparation of ores for principle chemical treatment by a series of relatively cheap processes (mainly physical rather than chemical in nature).

- They are designed to concentrate the valuable mineral and separate it from useless gangue and render the enriched material into the most suitable physical condition for the subsequent operations.

- In general these processes involve:

- Firstly, **breaking the ore** to such a small size so that the precious mineral is released or exposed from the gangue.

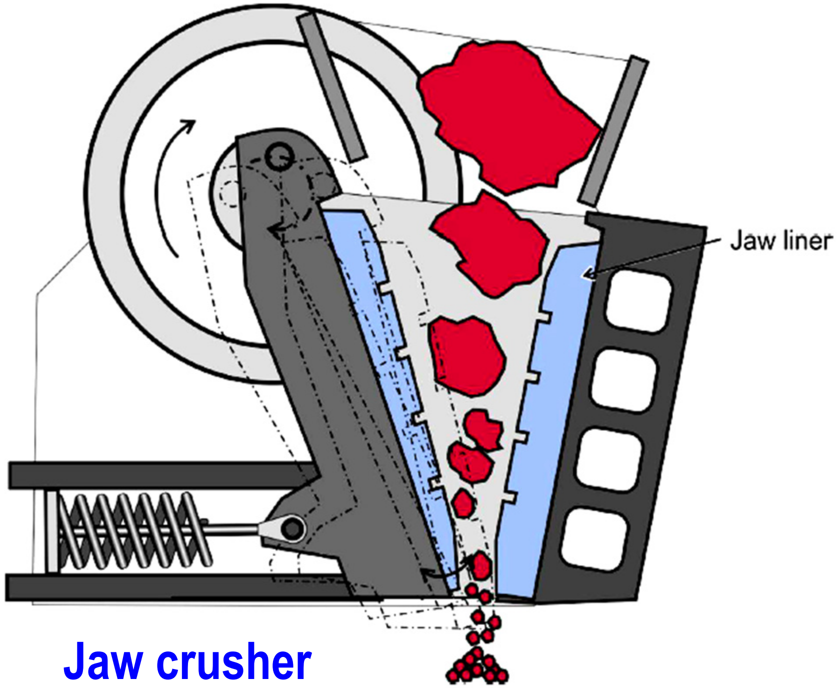
- Secondly, **a sorting operation** to separate the precious mineral from the gangue and sometimes to distinguish more than one valuable mineral from one another.

- Thirdly, if necessary, **to agglomerate (combine)** mineral particles to produce large particles.

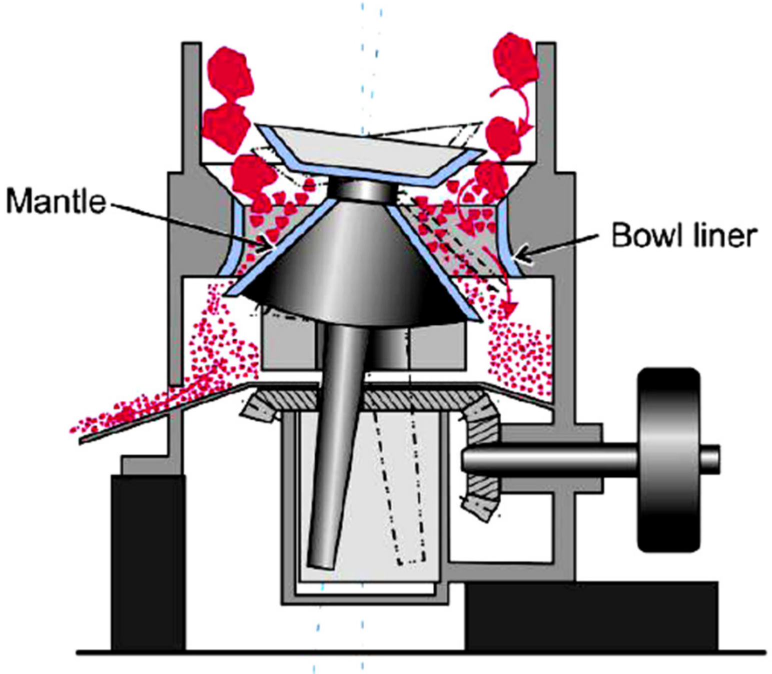
- The next stage of ore-dressing is to define the size to which ores should be crushed.
- Ideally, the ore would be broken down until every particle is valuable mineral or gangue.
- However, in practice, the ore is broken down to a satisfactory fineness (i.e. a range of sizes are inevitably obtained which are separated and processed or re-crushed, depending on the state of mineral/gangue association).

Types of Communition
(Ufalama Yöntemleri)

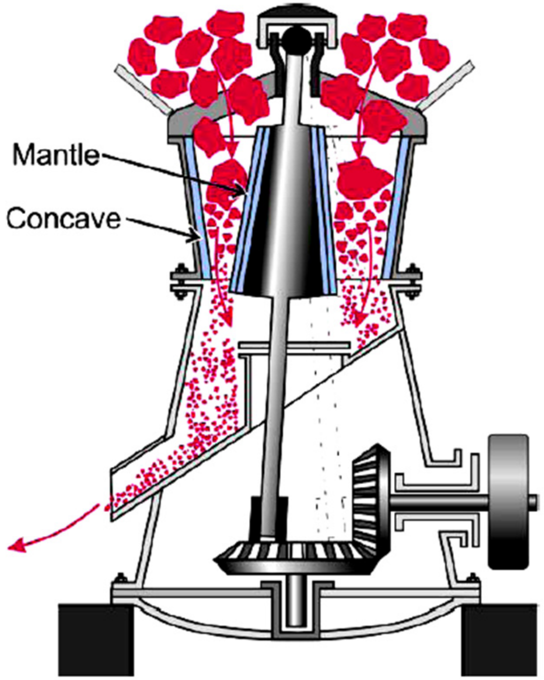
- **Crushing** (down to max. 1 mm)
  - **Primary Crushers:** Jaw, Gyratory, Roll
  - **Secondary Crushers:** Cone
  - **Tertiary Crushers:** Hammer, Impact
- **Grinding** (to smaller sizes)
  - **Thumble Mills** (with balls, pebbles, etc.)
  - **Stirring Mills** (usually with balls)
  - **Ring-Roller Mills** (with high velocity hot air)



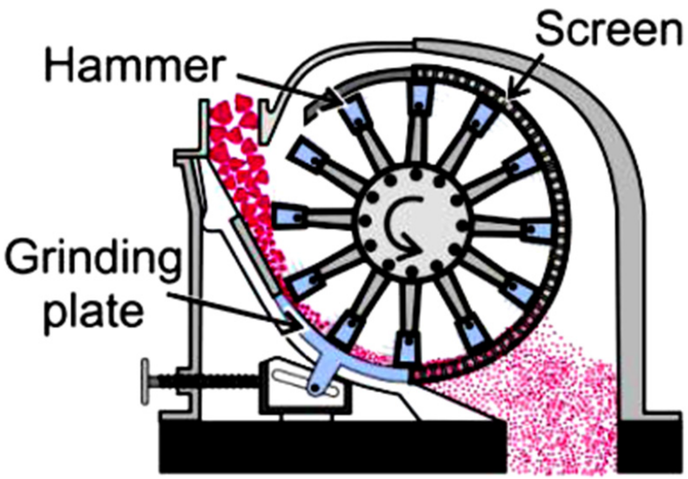
Jaw crusher



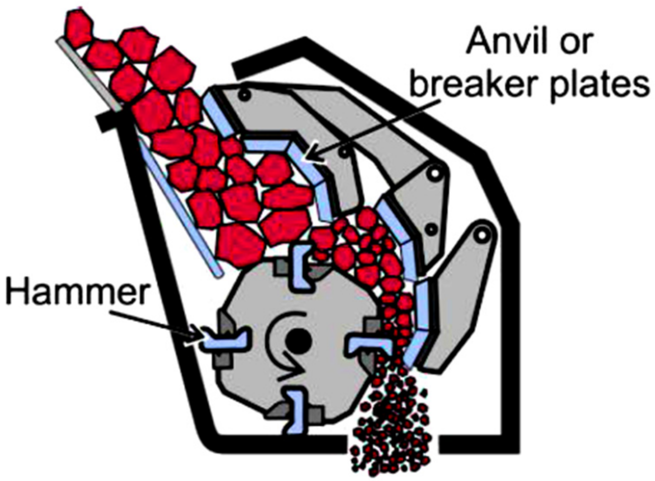
Cone crusher



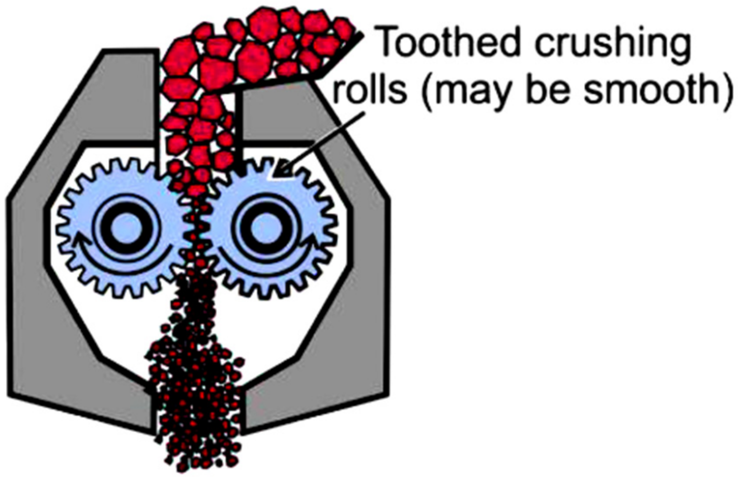
Gyratory crusher



Hammer mills

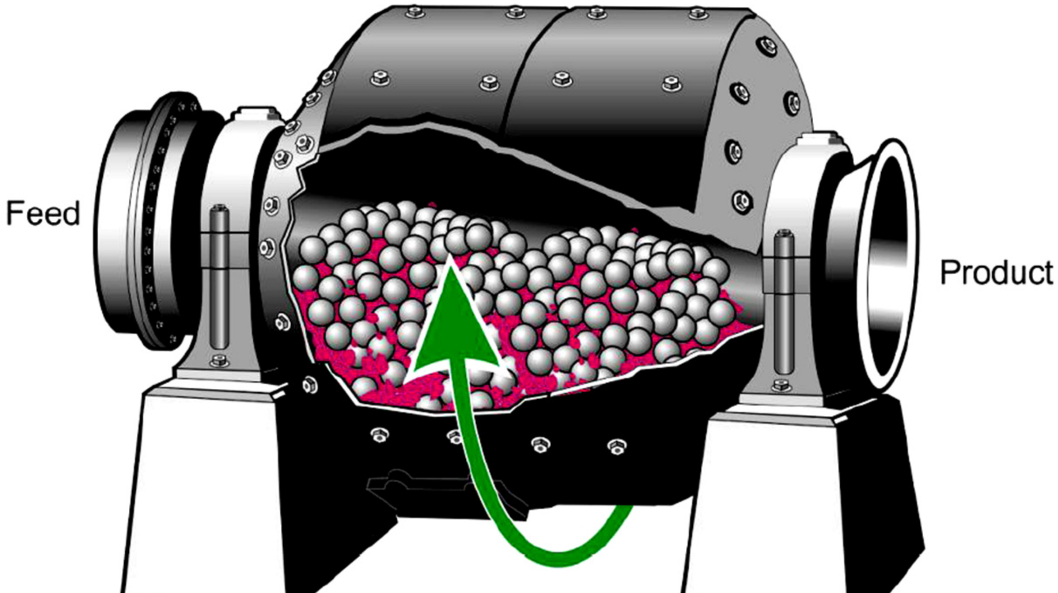


Impact breakers

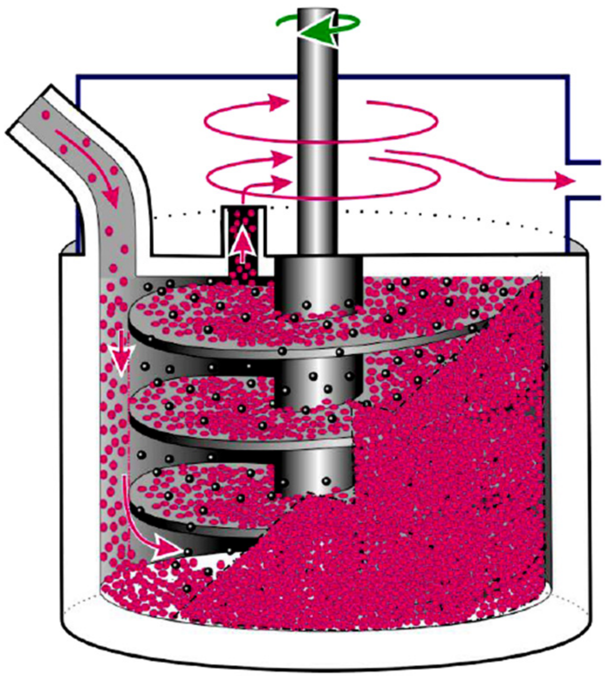


Roll crushers

Grinders (Öğütücüler)

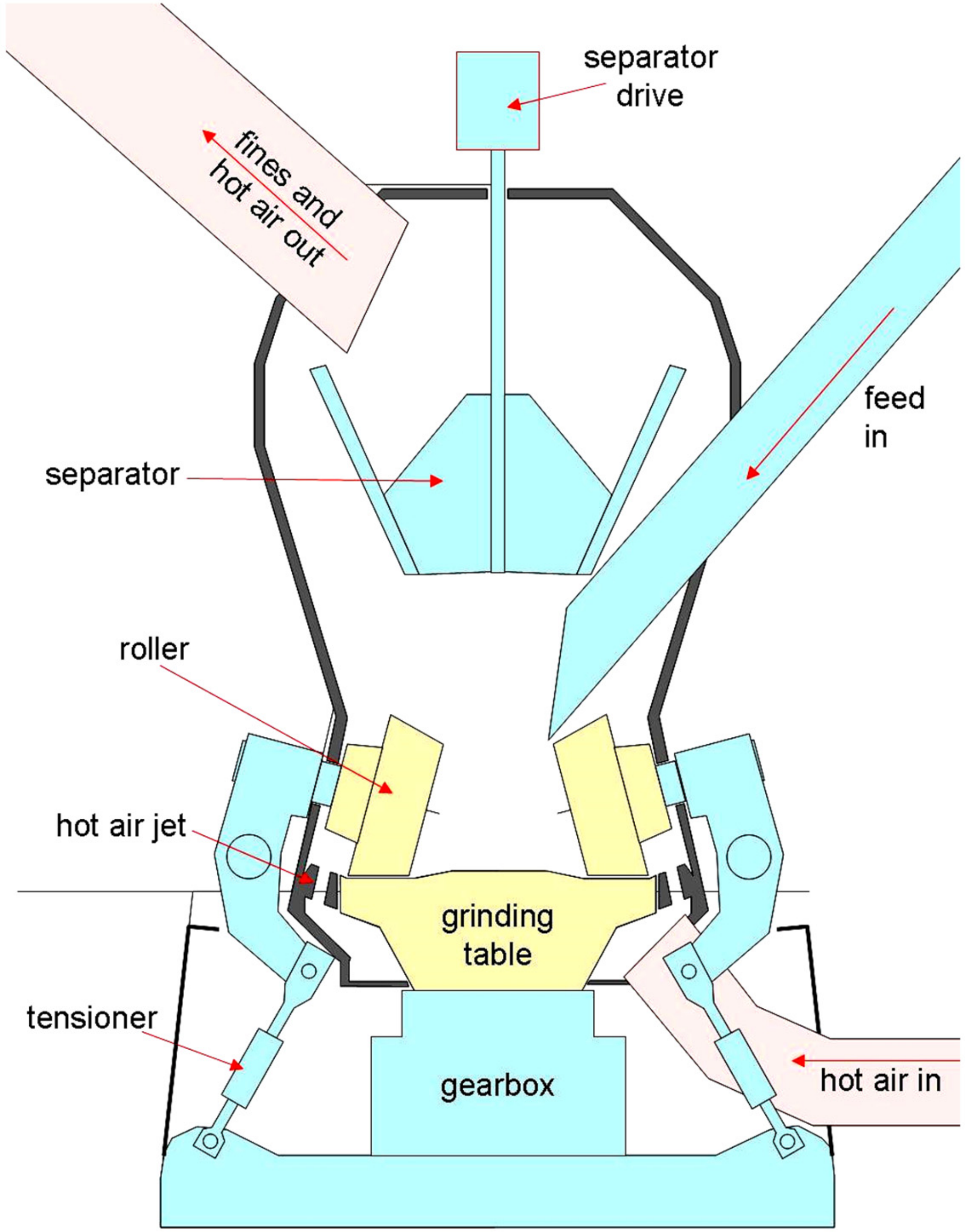


Thumble Mill



Stirring Mill

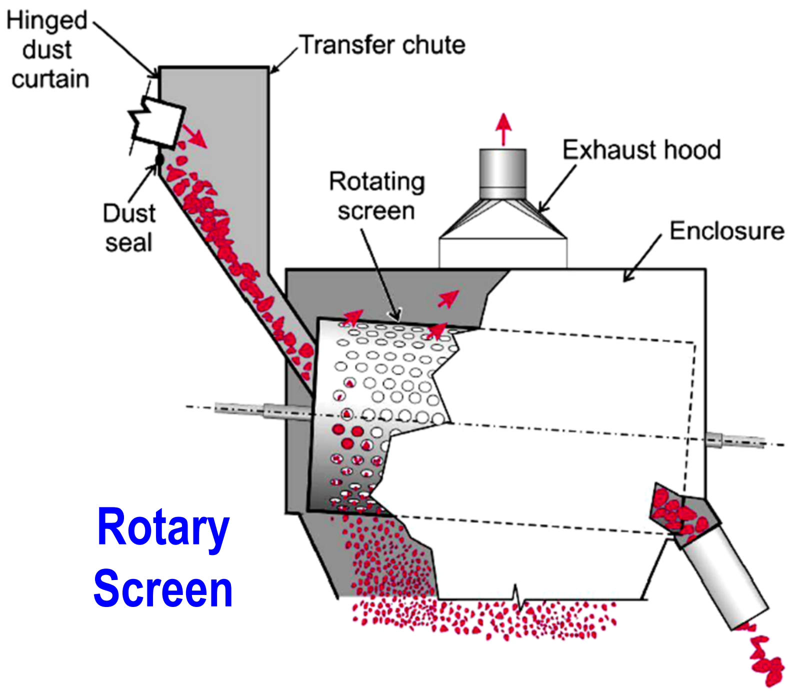
- Abrasive balls
- Product
- Shaft rotation

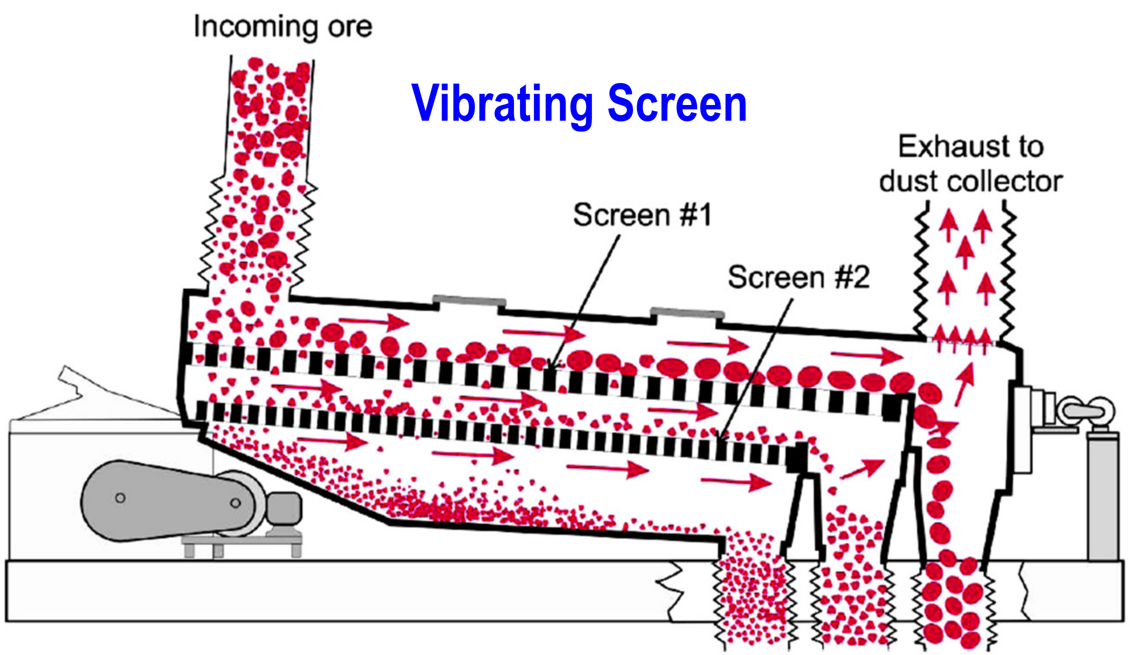


Ring-Roller Mills

Screening or Sieving (*elekten geçirme*)

- This is **the simplest, most direct sizing process**.
- Particles are passed through an aperture of appropriate size to separate undersize particles (passing through the opening) from oversize particles. It can be carried out using a range of aperture sizes to separate particles of various sizes.
- A screen is an assembly of such apertures of square shapes woven from fine wires. Aperture sizes range down to 50 μm, below which accurate fabrication of cloth is difficult.

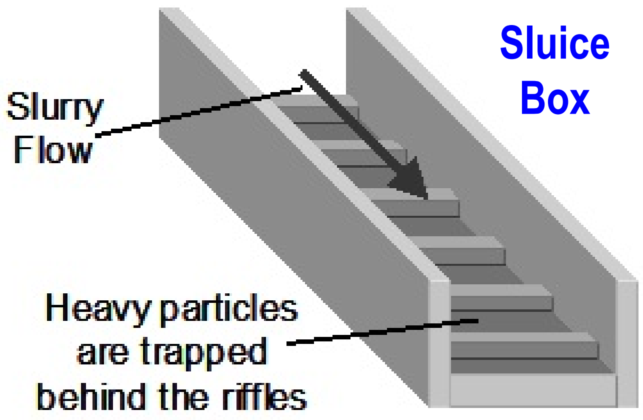




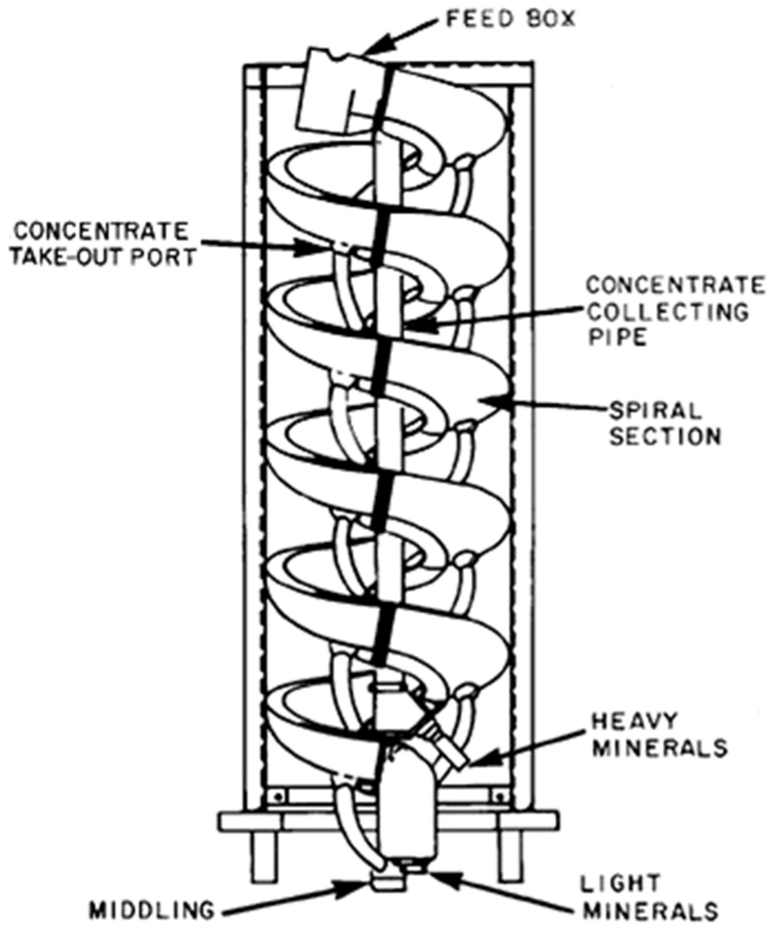
- **Sorting (*filtreleme*) processes** separate the valuable mineral from gangue, or in some cases, also affect a separation of different types of minerals.
- They are defined according to the physical property, which forms the basis of separation.

1. Classification (*çökeltme*)

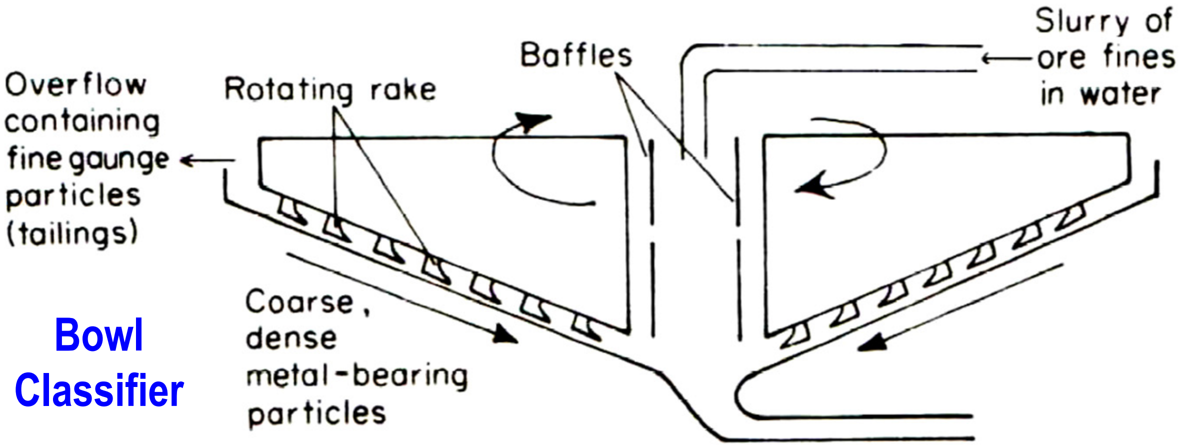
- Gravitational separation methods based on the rate of falling of particles in a fluid media (i.e. water).



Sluice Box



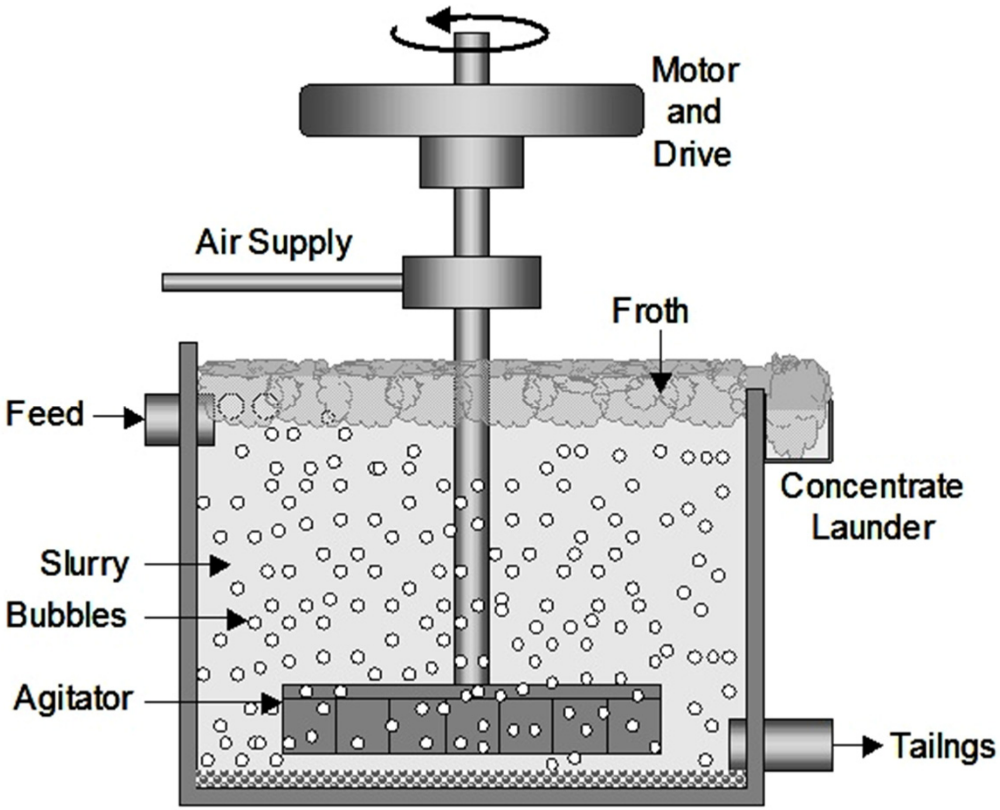
Humphrey's Spiral



Bowl Classifier

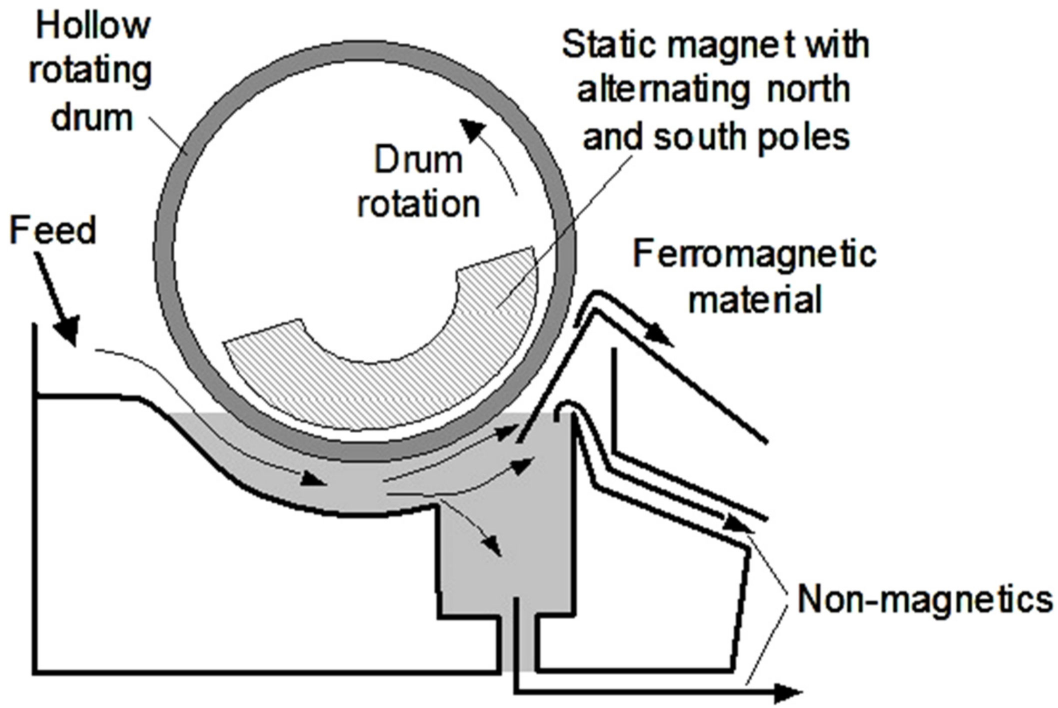
2. Froth Floatation (*köpükleme*)

- Occurs due to different surface free energies of different minerals.
- Slurry is agitated with air blown through it; certain minerals attach themselves to bubbles and are floated out in a froth.

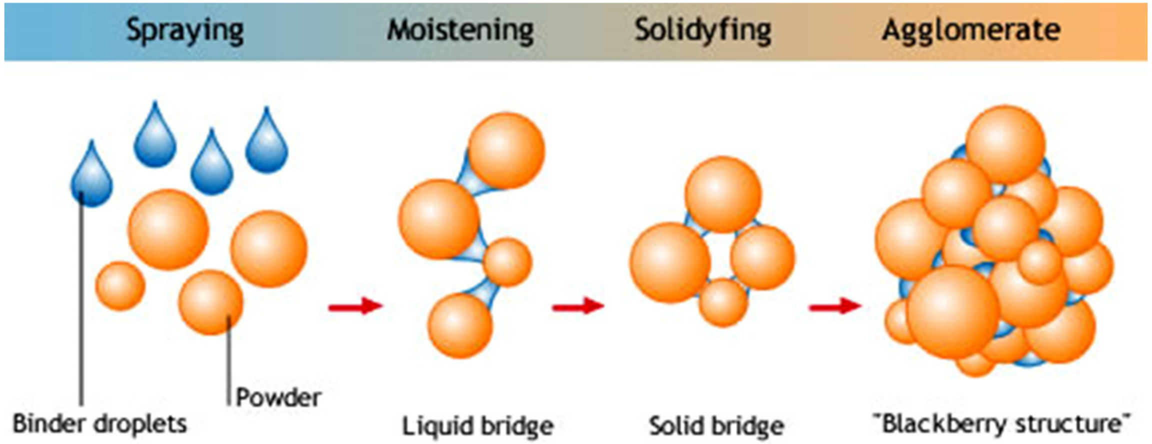


3. Magnetic Separation (*manyetik ayrıştırma*)

- Only few minerals are separated magnetically.
- Magnetic fields are obtained using permanent magnets on a drum, and magnetic particles are separated from non-magnetics.

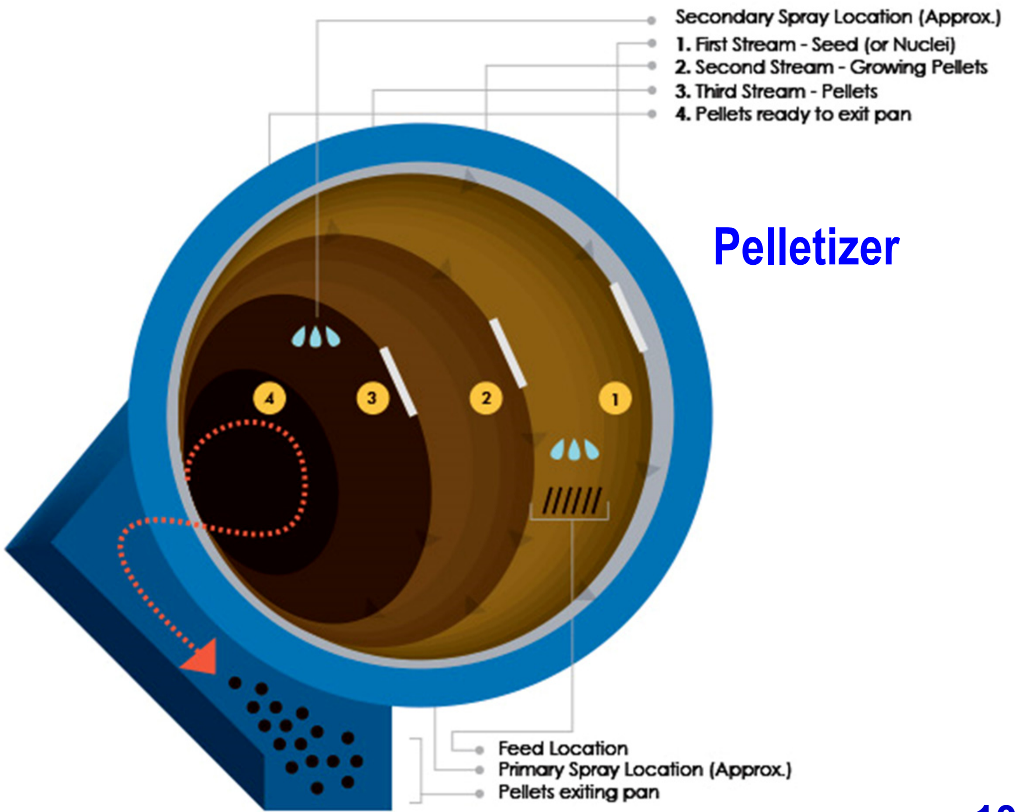


- **Agglomeration (*yığma*)** is process of converting very fine particles into lumps of appropriate size and strength.
- It is done by **pelletizing (briquetting)** at ordinary temperatures or by **sintering or nodularizing** at high temperatures.



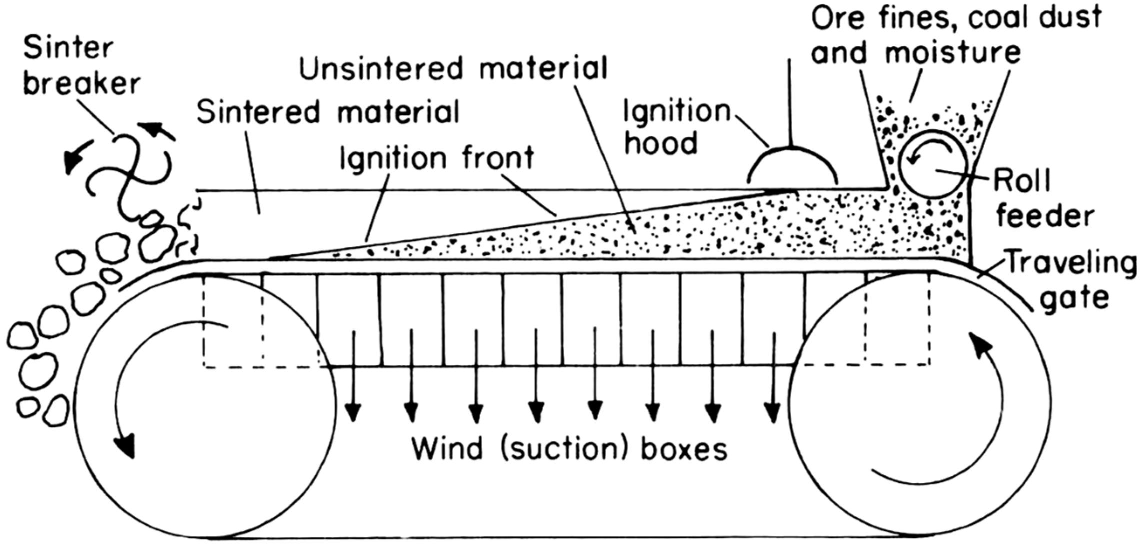
1. Pelletizing (*topak/yumak haline getirme*)

- Ore particles are mixed and moisted in a drum or rotating inclined disc. After that, they join together by capillary & surface tension forces as well as gravitational forces.
- Pellets may be used as green, but usually dried for better strength, derived from clay or glassy silicate bond (replacing water bond).
- Pellets are mainly used in iron-making. They can be made large (up to Ø4 cm) for feeding to the blast furnace, but Ø1 cm is preferable.



2. Sintering (*Sinterleme*)

- It is conducted at very high temperature (below the melting point) to allow diffusion between particles at points of contact, so that they can grow together to produce a rigid entity.
- It also involves chemical reactions producing **new chemical species**, whose crystallization provides the main mechanism for the formation of bridges between particles.
- **Dwight-Llyod sintering machine:** The charge (moist ores with coke dust) is ignited with a flame. The charge is dried out by hot gases, and combustion causes the oxidizing of sulphides and reduced oxides. Thus, sintering is completed by re-formation of oxides, which produces new crystals at the points of contact.



Dwight-Llyod Sintering Machine

3. Nodularizing (*boğumlu hale getirme*)

- Fine ores agglomerated in rotary kiln when heated until some components just begin to melt.
- Similar to pelletizing, but with a slag for bonding instead of water. This method **was formerly very popular** in iron-works in Europe, but **recently sintering is preferred**.

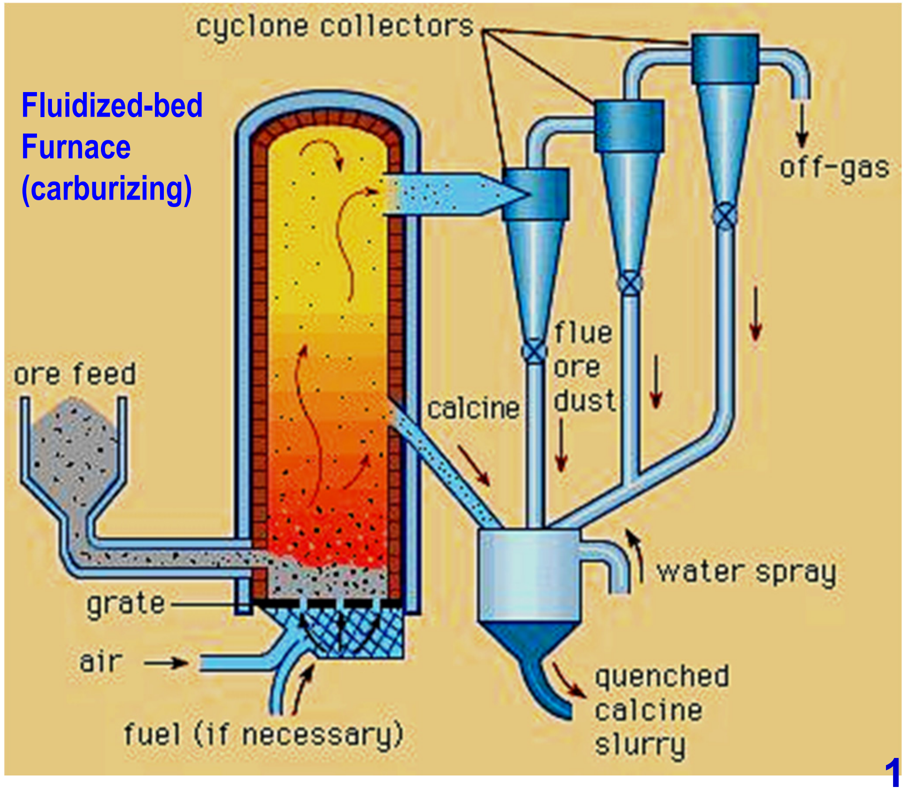
- Extraction processes **alter the ore chemically** by means of following ways:

1. Calcination (*yakarak toz haline getirme*)

- Thermal treatment of an ore to decompose into its constituents and to eliminate the volatile components (such water or CO_2).
- For instance; decomposition of **$CaCO_3$ (calcium carbonate)** occurs at 850 °C, so kiln (oven) temperature is kept at 1000 °C so that CO_2 can be obtained: **$CaCO_3 \rightarrow CaO + CO_2$**

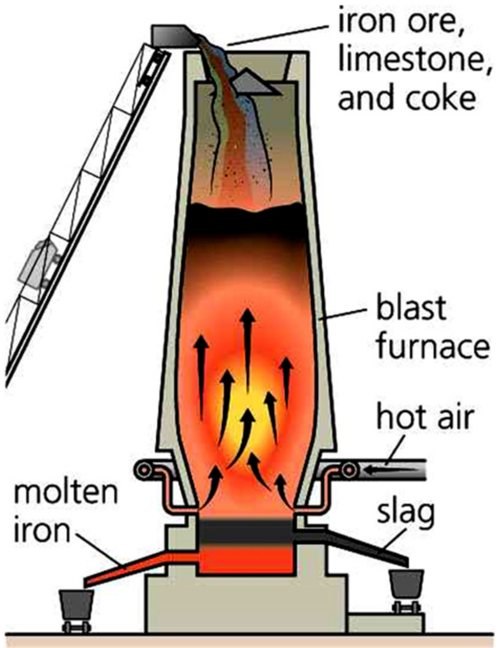
2. Roasting (*fırında pişirme*)

- Heating of ores in excess of air with spray of water
- **oxidizing:** converting sulphides to oxides
- **volatizing:** eliminating volatile oxides
- **chloridising:** converting certain metals to chlorides
- **sulphating:** converting sulphides to sulphates
- **magnetizing:** converting hematite to magnetite
- **reducing:** reducing oxides to metals
- **carburizing:** preparing calcine for chlorination
- **sintering:** sintering and oxidizing ore particles



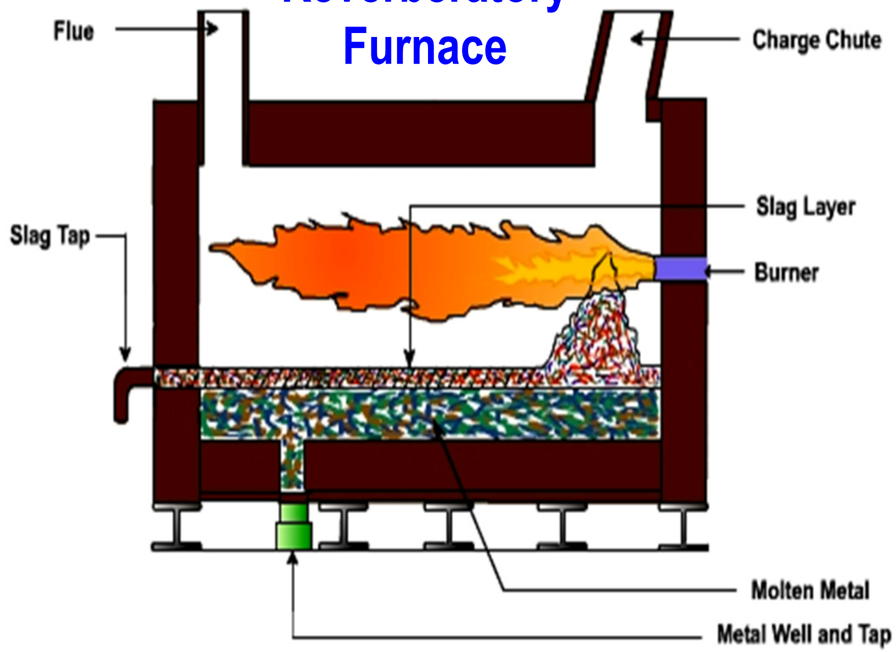
3. Smelting (*maden eritme/dökme*)

- A reduction (melting & separating) process to produce **matte** or **metal**.
- In **matte smelting** (e.g. copper), the undesirable products are removed by **roasting**. This roasted product is melted with a flux so that a rich matte is obtained along with a slag containing impurity metals. It is conducted in blast furnace (for lumpy ores) or reverberatory furnace (for fine ores).
- **Metal smelting** (e.g. pig iron) involves **reduction** (usually by carbon as coal or coke, but sometimes by ferrosilicon). Depending on type and/or properties of metal, it can be conducted in either or combination of blast, hearth, reverberatory or electric arc furnace.



Blast Furnace

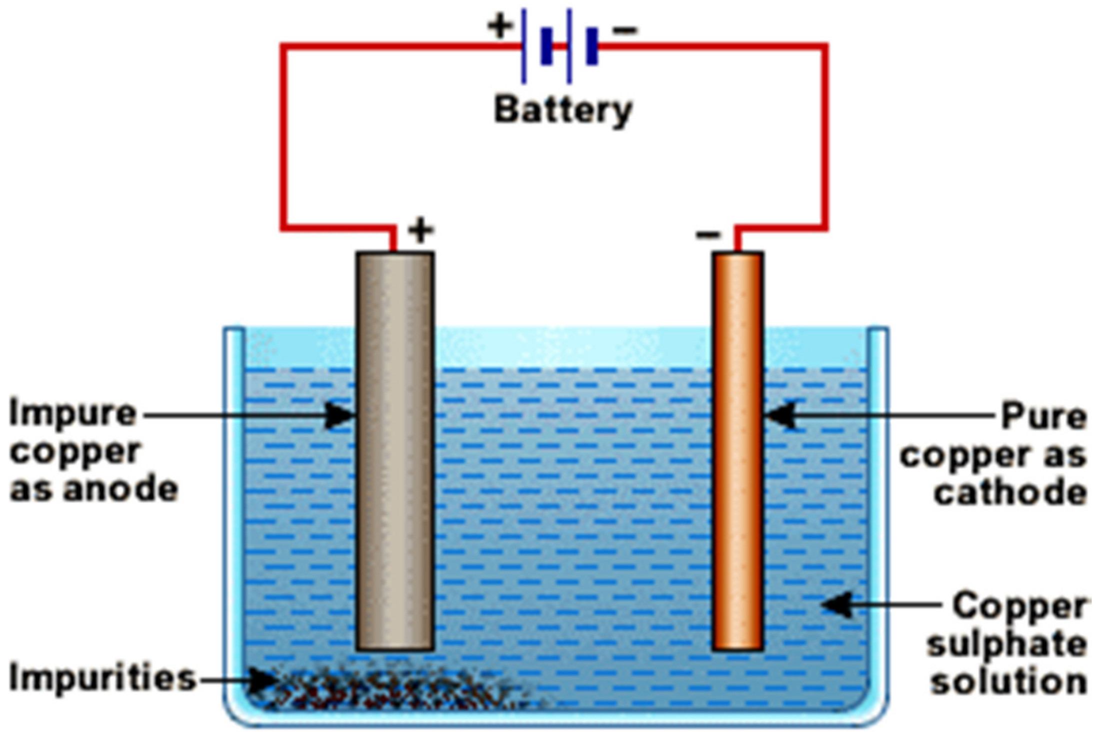
Reverberatory Furnace



4. Electrolysis (*elektroliz ile rafine etme*)

- A hydrometallurgical process used for both extraction and refining, in which **the electrolyte** is a solution or a mixture of fused salts.
- In extraction process, the metal is in solution (the electrolyte) from which it is deposited on cathode by passing a current through the solution, the anode being an insoluble conductor.
- In refining (purification) process, impure metal is the anode which dissolves in solution and redeposit on the cathode (i.e. pure metal) by passage of current through the solution.
- Figure shows electrolytic refining of copper.
- Copper sulphate solution contains ions of **Cu^{2+}** and **SO_4^{2-}**.
- Reactions below occur at anode & cathode when an electric current is passed:

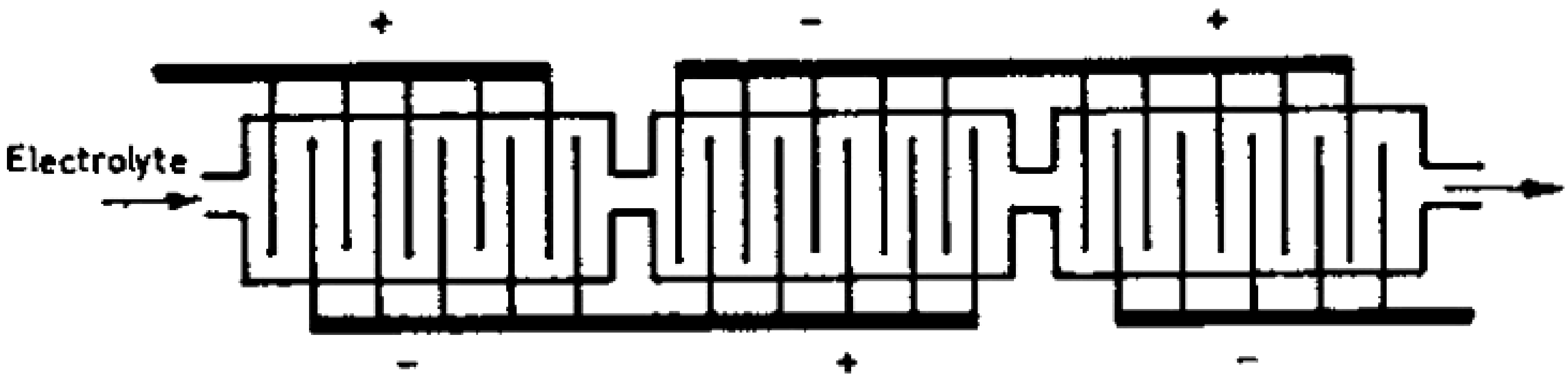
At cathode:	Cu^{2+} Copper ion (From electrolyte)	+2 electrons → (Reduction)	Cu Copper atom (Deposits on cathode)
At anode:	Cu Copper atom (From impure anode)	– 2 electrons → (Oxidation)	Cu^{2+} Copper ion (Goes into electrolyte)



4. Electrolysis (*elektroliz ile rafine etme*)

- The metals that cannot be electrolyzed from aqueous solutions may be deposited from **fused salts** or **igneous melts**. Fused salts are capable of decomposing metal compounds to free metal ions, which move freely in fused salt baths and are separated at cathodes on passing electric current (as in the case of aluminum extraction).

- In **electrolytic extraction plants**, electrodes are usually arranged in parallel in each tank, while large number of tanks are arranged in series (as shown in figure below). Tanks typically hold about 40-50 anodes and cathodes, each with an area of about 1 m^2. Current densities are usually in the range 100-300 A/m^2.



5. Fire Refining (*yakarak rafine etme*)

- The impurities are removed by heating the metal to its melting point.
- In some cases, cathodically-entrained hydrogen is removed by diffusion. In others, volatile impurities are drawn off under reduced pressure.
- **Most common case is steel**, in which impurities are removed by oxidation. Air (or an oxidizing slag) is used to oxidize impurities whose oxides are insoluble in molten steel. These insoluble oxides then combine with the flux to form a slag, which is separated from the refined steel. Gaseous impurities can be removed by vacuum degassing or by bubbling an inert gas through the melt.
- **Liquation** is a variant of fire refining: impure metal is heated to its melting temperature on an inclined surface. Upon reaching its melting point, the pure metal is viscous, and hence drains off leaving impurities behind. Conversely, the impurities may be lower melting and drain off leaving the pure metal.

6. Distillation (*damıtarak rafine etme*)

- The metal is heated to its boiling point, and its vapors are condensed to obtain pure metal.
- **Metals with low boiling point** at normal pressures (zinc, mercury, cadmium) are distillable.
- The impure metal is placed in a retort (tubular vessel), and retort is placed in a furnace. Desirable metal is vapourized by the heat of furnace, removed through the nose of retort, and condensed to produce the pure metal.
- Figure shows distillation of zinc using typical zinc retort.
- ZnO sinter is briquetted with coke before placing it in retort.
- Distillation can also be done **at lower pressures** where boiling point of metal is reduced.
- This is particularly useful for highly reactive metals.