Electrostatic Separation

Conductivities

Material	Conductivity (mho/meter)
Aluminum	3.5×10^{7}
Copper	5.8×10^{7}
Iron	1.0×10^{7}
Lead	4.5×10^{6}
Mercury	1.0×10^{6}
Nichrome	1.0×10^{6}
Silver	6.1×10^{7}
Tungsten	1.8×10^{7}
Amber	2.0×10^{-15}
Celluloid	5.0×10^{-9}
Glass, plate	5.0×10^{-12}
Rubber, hard	3.0×10^{-15}
Ivory	5.0×10^{-7}
Mica	5.0×10^{-16}
Quartz, fused	2.0×10^{-17}
Sealing wax	1.2×10^{-14}
Shellac	1.0×10^{-14}
Sulfur	1.0×10^{-15}
Wood, very dry	3.0×10^{-9}
Lucite, plexiglass	1.0×10^{-13}
Polystyrene	1.0×10^{-17}

Table 2.2. Relative Permittivities (Dielectric Constant) and Dielectric Strengths of Some Common Insulating Materials

Material	Relative Permittivity	Dielectric Strength (V/m)
Amber	2.8	–
Bakelite	4.9	2.4×10^7
Cellulose acetate	3.8	1.0×10^7
Mica	5.4	1.0×10^8
Plexiglass (lucite)	3.4	4.0×10^7
Polystyrene	2.5	2.4×10^7
Porcelain	7.0	6.0×10^6
Titanium dioxide	90	6.0×10^6
Barium titanate	1200	5.0×10^6

ES Separation

Separating 2 or more solids in air employing ES

1. Benefication of ores.
   – Ilmenite, rutile, zircon ,apatite, asbestos,hematite
2. Purification of food
   – Removal of rodent excrements and trash from cereals
3. Separating fiber from wires
4. Sizing of Particles – size/shape dep.

TABLE 10.1

- 14 M tonnes – produced – 95% mineral beneficiation
- 1880-purifying ground cereal
- 1892-Edison – gold ore concentration
- First commercial- Platville- Wisconsin - lead zinc(1908)

Table 10.1. Industrial Separations Made by Electrostatics

Arsenopyrite–feldspathic gangue	Mica–feldspars/silicates
Asbestos–silicates	Molybdenite–silicates
Barite–silicates	Monazite–beach sands
Chromite–ilmenite–magnetite–monazite	Nickel–copper ores–metasilicates
	Rutile–beach sands
Coal–pyrite	Scheelite–pyrite
Coal–shale	Silicon carbide–alumina/silicates
Cobalt–silver–silicates	Spodumene–cassiterite
Coke–iron	Stibnite–silicates
Copper ore–silicates	Wire–thermoplastics/rubber
Copper wire–insulation	Wolframite–pyrite
Diamonds–silica	Zircon–beach sands
Feldspar–mica gangue	Bark–sand
Feldspar–quartz	Barley–rodent excrement
Fluorite–silicates	Cocoa beans–shell
Fly ash–carbon	Cotton seeds–stems
Gold/platinoids–beach sand	Movie film–paper
Gold/platinum–jewelry sweeps	Nut meats–shells
Graphite–silicates	Peanuts–shells
Halite–sylvite	Plastic–lint
Ilmenite–garnet	Polyvinals–polyesters
Ilmenite–beach sand	Rice–rodent excrement
Iron (specular hematite)–silicates	Seeds–foreign material
Kaolin–iron contamination	Soap–detergent
Kyanite–rutile and iron gangues	Soybeans–rodent excrement
Limestone–silicates	Walnuts–shells
Magnetite–silicates/rutile	Wheat–garlic seeds

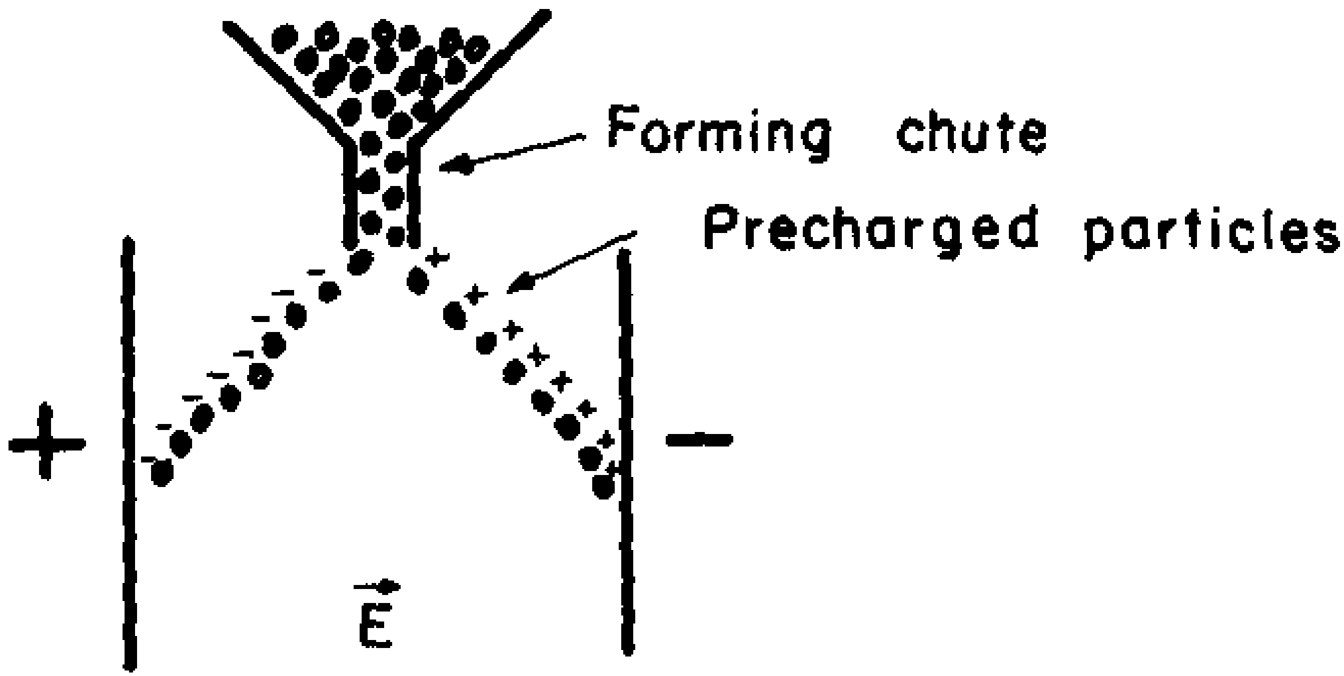
- Singly(+ Gravity)
- 1912-froth floatation developed-Low capital cost
- Picked up in wwII-Titanium shortage
- Developments in HV Power supplies
- HT Separator- supplement and with a capacity of 6 MT/year
- 1965- wabush mines-canada
- Sio_2 content 8 to 2% $ -0.05/ton of dry feed
- -Dry
- -does not require any chemical reagents.

- ES selective sorting – utilizing forces acting on charged or polarized bodies in E fields.
- Charging Mechanism: Selectively charging the species-separate zones.
- Particles of 2 species – separate zones

eg: Phosphate (+ve netcharge) from Quartz (net –ve charge)

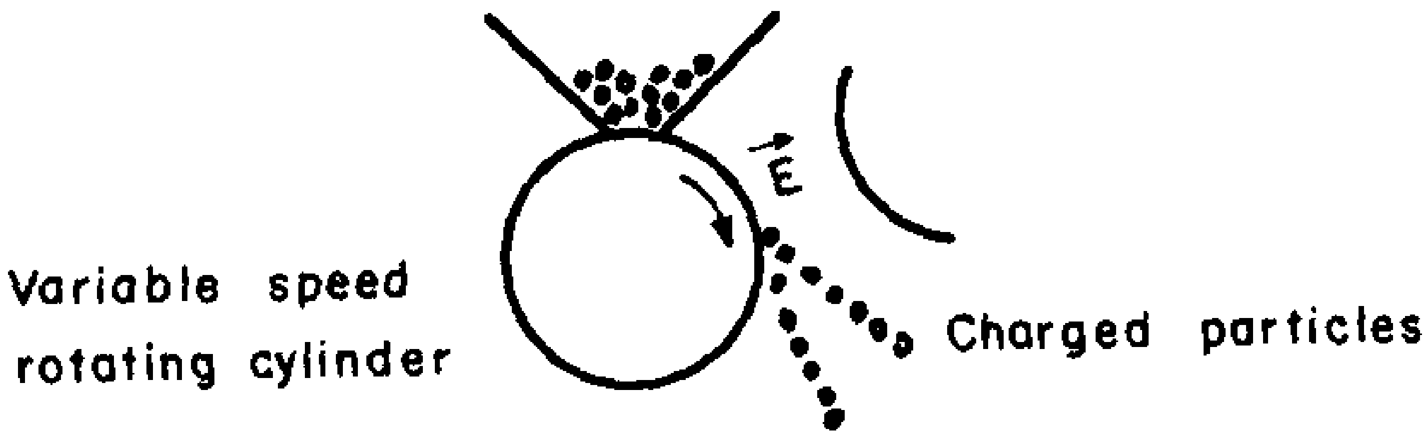
- Particles of 2 species – one type bear significant charge
- Magnitude of charge proportional to the size
- different dipole moment.
- External Electric field 10- 100kv – unidirectional

forming chute



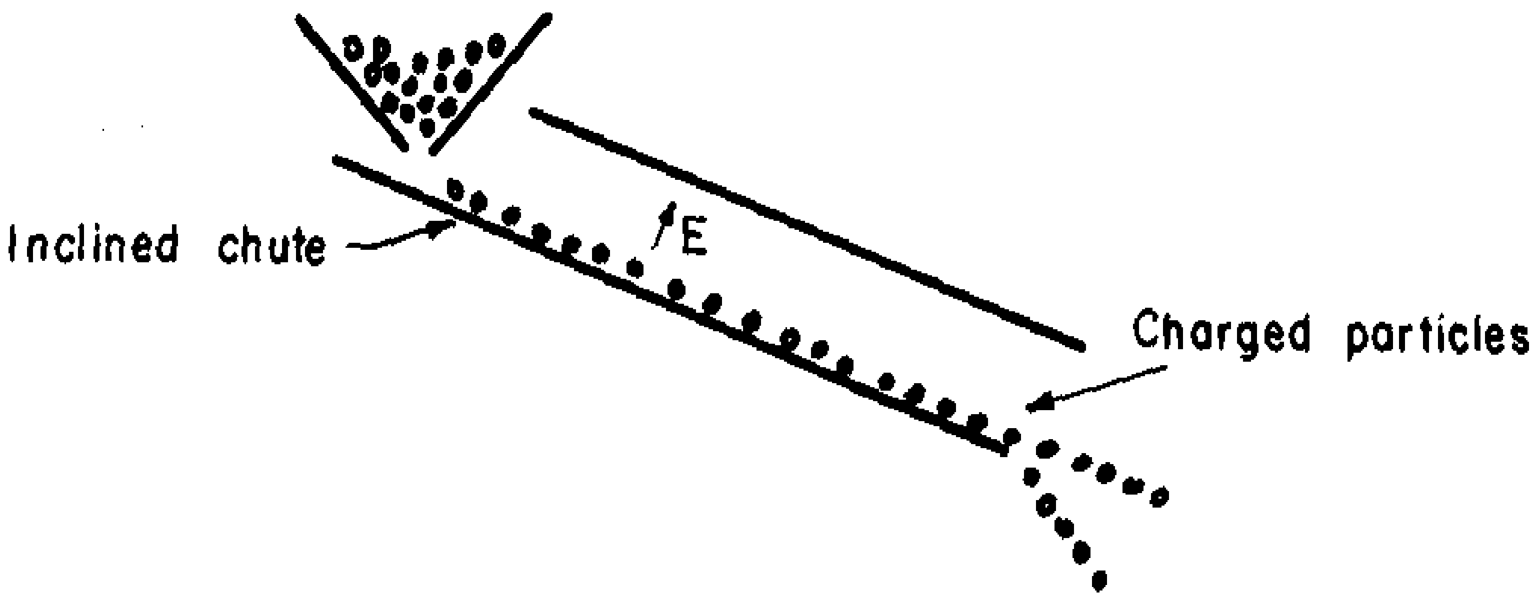
(a)

variable speed rotating cylinder



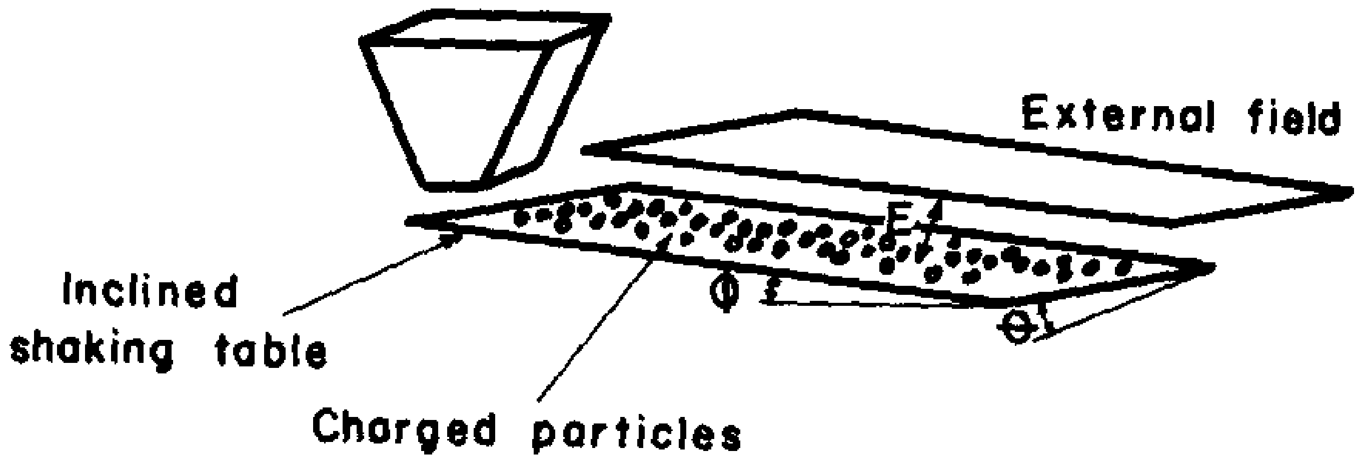
(b)

inclined chute,



(c)

inclined shaking table.



(d)

- <u>Non electrical particle trajectory Regulator</u>
- Physical separation – Adjust forces and time of action
- Different Particles – different trajectory Pre determined time
- Electrical (ES) +Gravity +centrifugal +Friction

- Forming chute – initial velocity Adjusted by gravity
- Variable speed cylinder- adjust centrifugal forces (rotating)
- Inclined chute
- Inclined shake table.
- <u>Feeding and collection system</u>
- Means of conveying feed
- Mean of cutting to collect

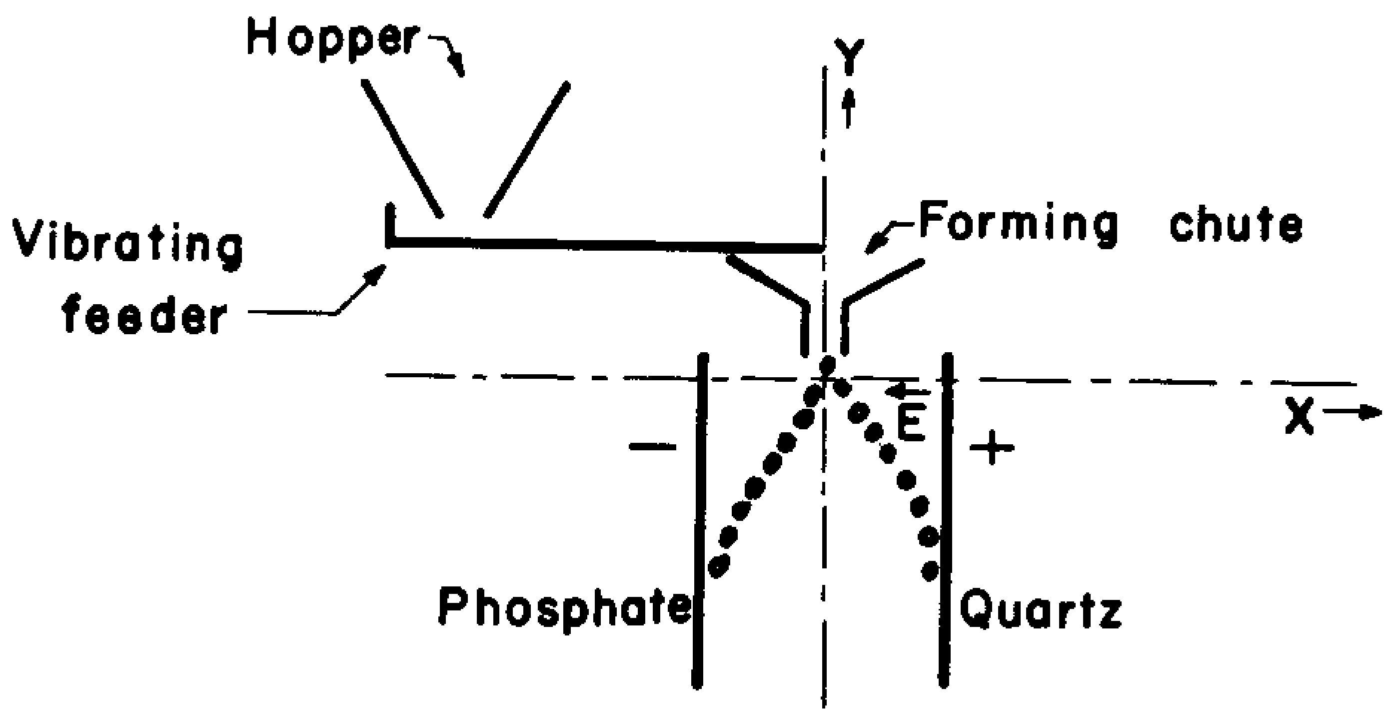
Charging Mechanisms

1. charging by contact and Frictional electrification - Inherent(active) – particles make and break a contact- when sliding over a chute – or electrode
2. Charging by ion or e^- bombardment
3. Charging by conductive induction - When particles touch grounded electrode in E field

- Contact electrification and free – fall separator- selectively charge- separate 2 species of dielectric materials

eg: Feldspar- Quartz, Quartz-Apatite, Halite- Sylvite - conductors-charge but lose before separation

- Common experience- combining hair on a dry day people with long hair specially girls/women - observe sparks-by combining in dark
- Comb- one polarity and hair –opposite polarity
- Shock upon contacting metal door knob after walking over thick carpet.


Hopper
Y
Vibrating feeder
Forming chute
X
E
−
+
Phosphate
Quartz

- Contact electrification Coehns rule- Higher ϵ_r gets charged +ve
- Zwikker - greater no. of energy levels- higher ϵ_r easily polarized by releasing e-
- Beuch - surface charge density 15x10-^{6} ($\boldsymbol{\epsilon_1 - \epsilon_2}$) C/m^2 at contact break.
- In air not > 26.6x 10^{-6} C/m^2.
- Henry- considered ionic surface with inter-atomic space of 3.2 A
- Each ion-10A2
- 1m^2 = 1x 10^{19} ions or 5 x 10^{18} ions
- Each ions of 1.6x10^{-19}C – 8x10^{-1} C/m^2
- Hence 0.003%
- 400 substances-tested Cohen's rule

- Say 2 spherical particles- different chem. Compositions
- Quartz and Apatite – equal and opposite charge clean and dry by contact charging - 40^0 to 800^0 → calcium phosphate + Flouride . Qaurtz – negative and Apatite -Positive
- Charged particles dropped through E field
- Trajectory in opposite directions
- Neglect- Coulombic forces on particles due to neighbouring particles
- Let E = Electric Field V/m Q = charge on a particle 'C'

  = $\Sigma \sigma_s$ – surface charge g= gravity . t= time m= mass F =force

  Electrical = QE = m d^2x/dt^2

  Fgravity = mg = $-md^2y/dt^2$

  Say initial velocity and displacements are zero

  X = ½ (QE/m) t^2 – Horrizontal.

  Y = $-1/2gt^2$ - vertical

- 0.25 mm dia. Q/m $9x\ 10^{-6}$ C/kg
- $E = 4x10^5$ V/m
- $X = 1/2x(9x10^{-6}x4x10^5)\ t^2= 1.8\ t^2 m$
- Time required for fall 0.5m is $[(0.5x2)/9.8]^{1/2} = 0.1^{1/2}$ s
- X = 18 cm =>2 X = 36 cm
- X ⌉ α Q
- Y ⌋ α E

α 1/m

E limit – $3x\ 10^6$ V/m

$\int E.dA = Q/\epsilon_0$

Consider sphere – $\sigma C/m^2$

$EA = \sigma A/ \epsilon_0 = 9x\ 10^{-12} F/m$

$\sigma_{max} = E_0 = 26\ x\ 10^{-6}\ C/m^2$

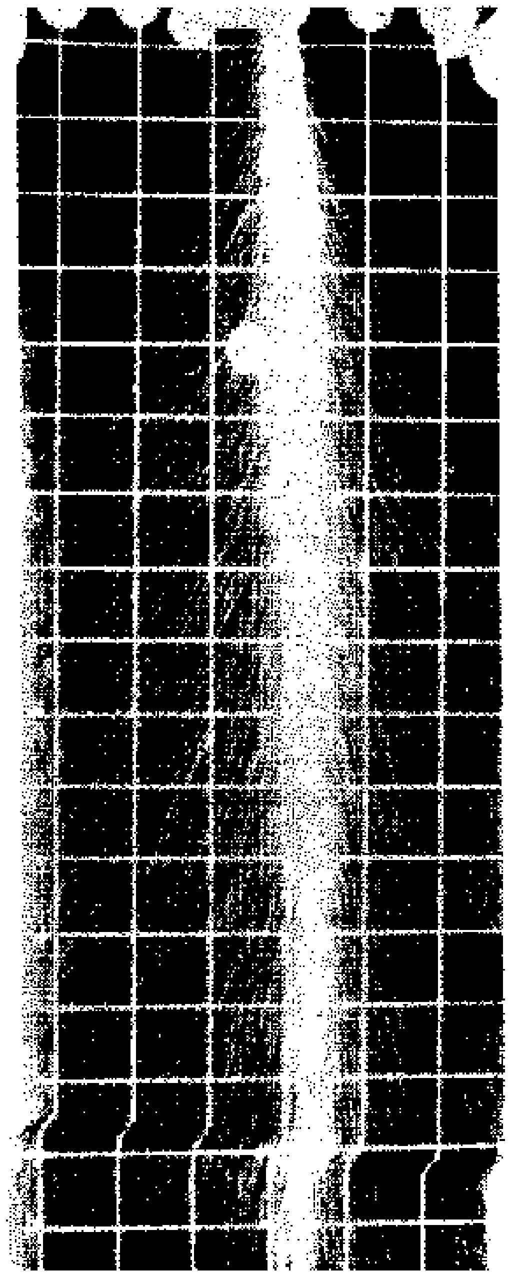
Radius r

$Fe = QE = 4\pi r^2 \sigma E$

$Fg = 4/3\ \pi r^3 \rho g = 9.8\ m/s^2$

ρ -- density

- $Fe/Fg = 4\pi r^2 \sigma E / (4/3\ \pi r^3 \rho g) = 3\sigma E/(r\rho g)$
- It is possible to increase the electrical force acting on charged particles by working under high pressure, since both the limiting value of particle charge density and the external electric field are raised with increasing pressure.
- Air at 1 atm.
- $E = 3 \times 10^6$ V/m
- $\sigma = 26.6 \times 10^{-6}$ C/m^2
- $g = 9.8$ m/s^2
- $Fe/Fr = 25/(r\rho)$
- σ = 5% of max. and E=80% max
- $Fe/Fg = 1/(r\rho)$ 10 mesh or r=1 mm
- $Fe/Fg = 1/3$ Mesh 3
- As the density increases , the upper size limit decreases.. The lower size limit is determined by the particle size distribution where fines tend to form clusters by inter particle Coulombic forces and cease to be separated by the external electric field.
- Lower limit- 20μ



Product	%Wt	% Phosphate	%Quartz
Feed	100	50	50
Concentrate	47	97.1	2.9
Tail	53	8.2	91.8

Feed rate = 200 lb/((hr)/(in.)) of electrode width

Electrode spacing = 6 in

Potential difference between electrodes = 60 kV

Particle size = 0.15 to 0.30 mm diameter

<u>High –Tension Machine</u> Ion bombardment

Good conductor from bad conductor.

-Ilmenite and Rutile from quartz

-Hematite from quartz

-Chopped copper wire from insulation

- take advantage from Corona – usual – charging ions or electrons

- Pass solids through the corona discharge from a wire or a series of needle points positioned parallel to a grounded rotor of a separating machine.
- When wire/needle raised to a high potential corona begins
- E α 1/r (conductor radius)
- Corona – depends on polarity
- If electrode is positive negative ions are accelerated towards the electrode, causing the breakdown of air molecules with the result that positive ions are repelled outward from the electrode in the form of corona glow.
- Involves small current flow
- Electrodynamic separators
- Charging by passing solid over grounded rotor through corona from a wire charged to potential greater than 30 kV/mm
- Conductors are quickly discharged through rotor and thrown by centrifugal force, gravity and air resistance.
- Dielectrics lose their charge slowly and are held on the surface.

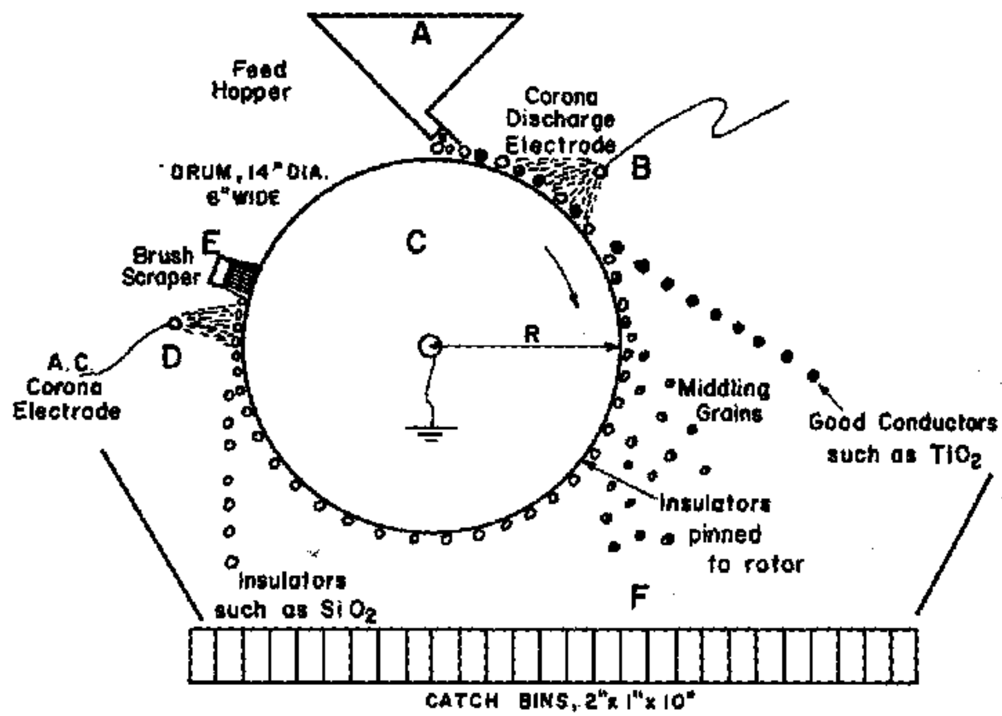
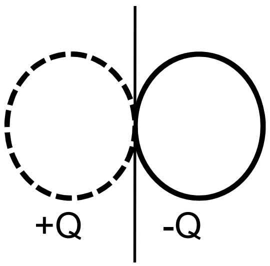


Figure 10.4. High-tension separator.

- By image forces
- They are scraped from the back side by a brush.
- Charge ion α electrical resistance
- $Fe = m\,\omega^2 R$
- Where m = particle mass
- ω = angular velocity
- R= radius of the rotor



$F_{image} = (1/4\pi\,\epsilon_0)Q1Q2/(2r)^2$, $\nabla^2 V = 0$

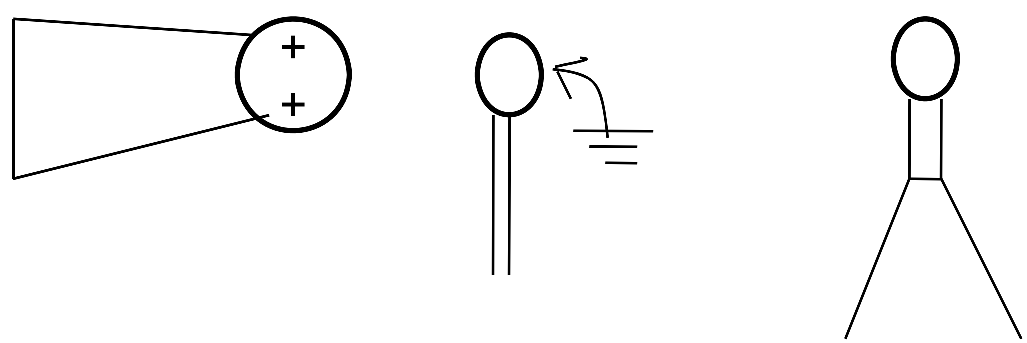
- Grounded infinite plane
- 0.3 mm dia quartz particle is about 5.8×10^{-6} C/m²
- 14-in. Diameter drum rotating at 70 rpm.
- $F_{image} = 1/(4\,\pi\,\epsilon_0)\text{x}\,(4\pi r^2 \sigma)^2/(2r)^2 = 36\text{x}10^{-9}\text{x}\pi^2 r^2 \sigma^2$
- $Fc = 4/3\,\pi r^3\,\rho\omega^2 R$
- $Fi/Fc = 8.5\times1010\sigma^2/(r \times \rho \times \omega^2 R)$ pinning factor

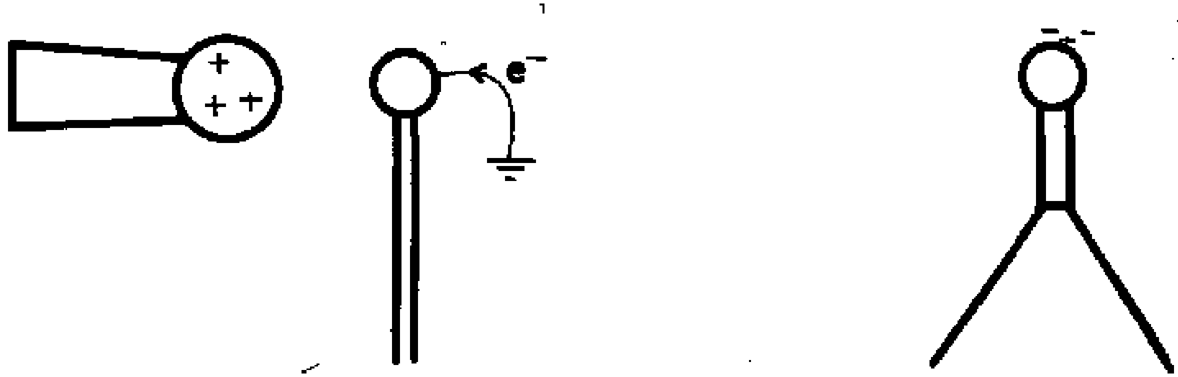
- $\sigma = 5.8 \times 10^{-6}$ C/m^2
- $\rho = 2.65 \times 10^3$ kg/m^3
- $R = 1.5 \times 10^{-4}$ m
- $\omega = 7.9$ rad/sec
- $R = 1.78 \times 10^{-1}$ m
- Fi/ Fc = 0.7
- The pinning factor increases as particle size, density, and $\omega^2 R$ are decreased. The pinning factor also increases as the square of the surface charge density σ_s. Time is no consideration.
- Large insulating particles from small conductors, closely sized feed.
- $Q = \Sigma\sigma_s$.
- $i = dQ/dt = -K\, \Sigma\sigma_i/R_T$
- $= (-K/R_T)Q$
- $Ln_\epsilon Q = -Kt/R_T + C \quad C = \ln Q_0$
- $Q = \rho_{0\epsilon}{}^{-Kt/R_T}$

- $R_T = \Sigma$ volume, surface and contact resistance
- $Q/Q_0 = 1/_\epsilon \quad T_R = R_T/K$

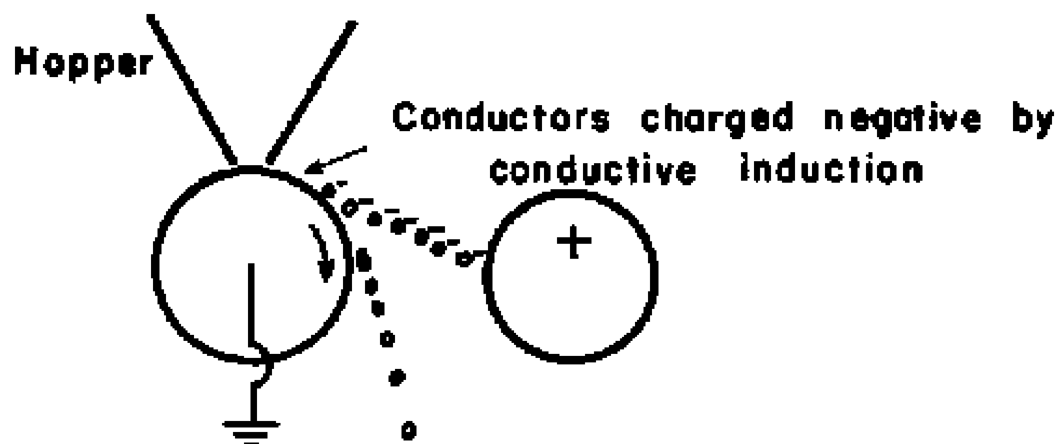
- Pyrite $T_R = 10^{-3}$ s
- Quartz = 106 sec.
- R_T = det.separate

- <u>Charging by Conductive Induction</u>
- Separation of good Elect. Conductors from Good Insulator.
- Also – 2 or more semiconductors
- School- electroscope
- Uncharged electroscope grounded with the finger in the presence of a charged body- when charged body leaves diverge





(a) (b)

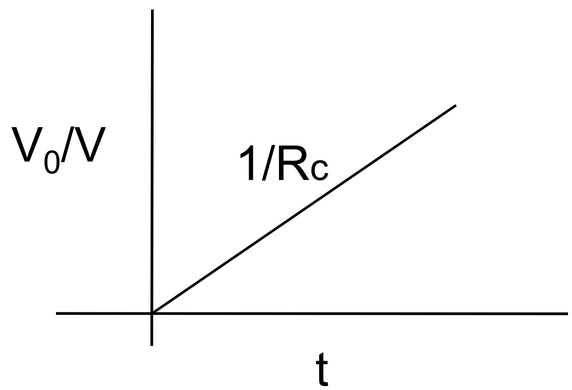

Hopper
Conductors charged negative by conductive induction
+

- particles pass over a grounded rotor – in presence of external field.
- Conduction Separator
- Good Conductors – quickly charged by induction - Attracted by external electrode
- Poor conductor – feebly charged
- Corona discharge more useful
- Food and drug Industry employs
- Feed Preparation
- Success of separation – key
- Material $\pm$ one dia of the mean particle size.
- Foreign material over surface removed – air/water
- Table 10.2
- Surface of particles be dry and hot

Table 10.2. Ten Typical Industrial Separations and the Surface Treatment Required for Each

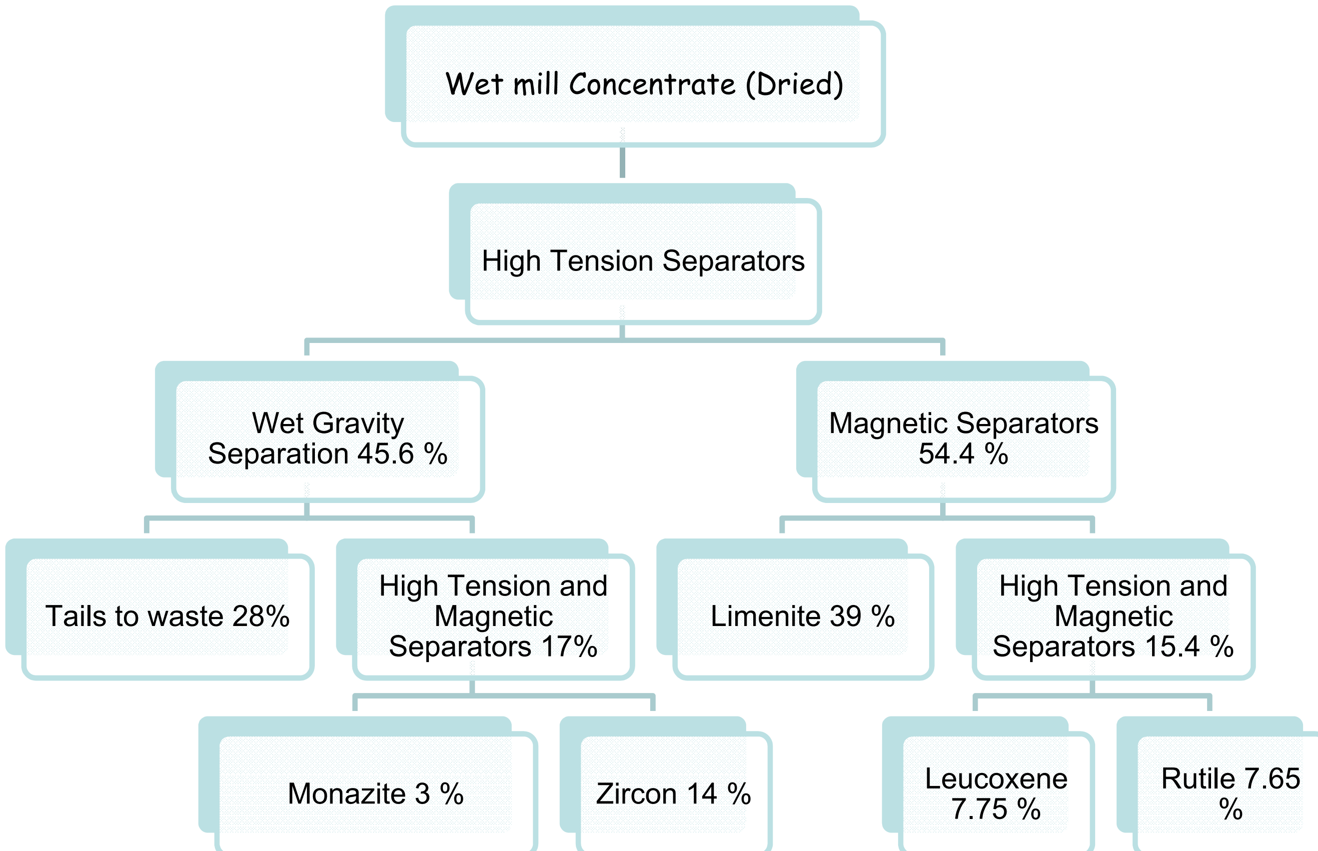
Mineral Combination	Surface Treatment	Usual Charging Mechanism
Specular hematite–quartz	Drying	Corona discharge
Ilmenite and rutile from poorly conducting, heavy mineral gravity concentrates (zircon, monazite, etc.)	Scrubbing to remove organic slimes; drying (reducing roast at 650°C)	Corona discharge
Zircon (cleaning)–ilmenite, rutile	Drying	Corona discharge
Cassiterite–scheelite	Drying	Corona discharge or conductive induction
Feldspar–quartz	Drying; HF vapors	Contact electrification
Halite–sylvite	Heating to 340°C or drying plus 1 lb/ton of fatty acids	Contact electrification
Pyrite–coal	Drying	Corona discharge or conductive induction
Coal–shale	Humidity control	Corona discharge or conductive induction
Diamonds–silica	Wet scrubbing in NaCl pulp; drying	Conductive induction
Dry foods and drugs from trash and rodent feces	Drying	Conductive induction

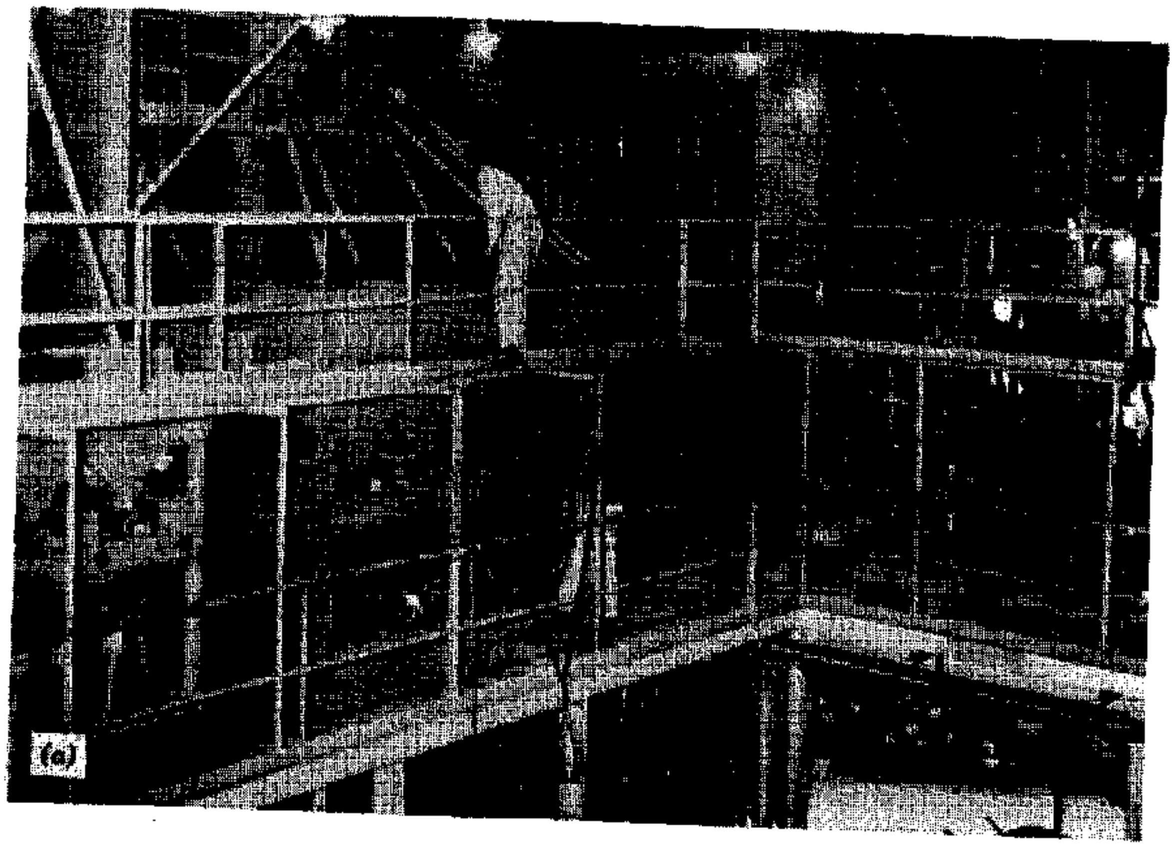
- Lab Techniques
- Charge on solids – Faraday pail, Electrometer
- Keithley – 610A (Zi/p > 10^{14} Shunted by 30 pF)
- Apparent particle resistivity – R_T
- Conductivity cell
- $V = V_0 \epsilon^{-t/RC}$
- C is the value of the capacitor of the circuit
- Rc – cell resistor
- $\rho = (2\pi LR)/(\ln b/a)\ \Omega m$



- Once the value of Rc has been approximated, the resistivity of the powdered sample can be computed by the following well-known expression of the leakage current in a sheathed cable:

- <u>Industrial Applications</u>
- Corona Discharge

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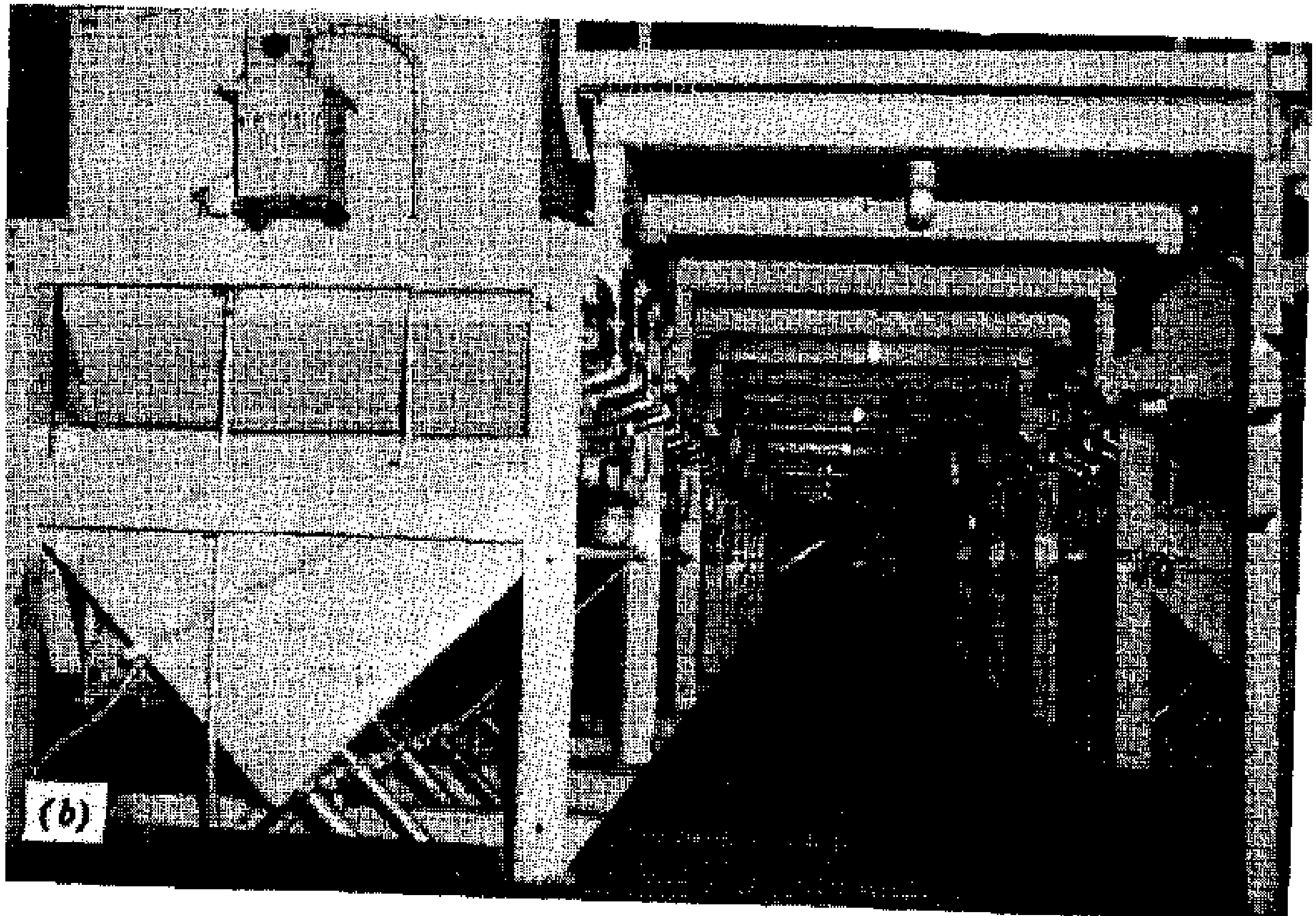

igure 10.12. High-tension plant for heavy minerals.

Figure 10.13. High-tension section of Wabush plant.

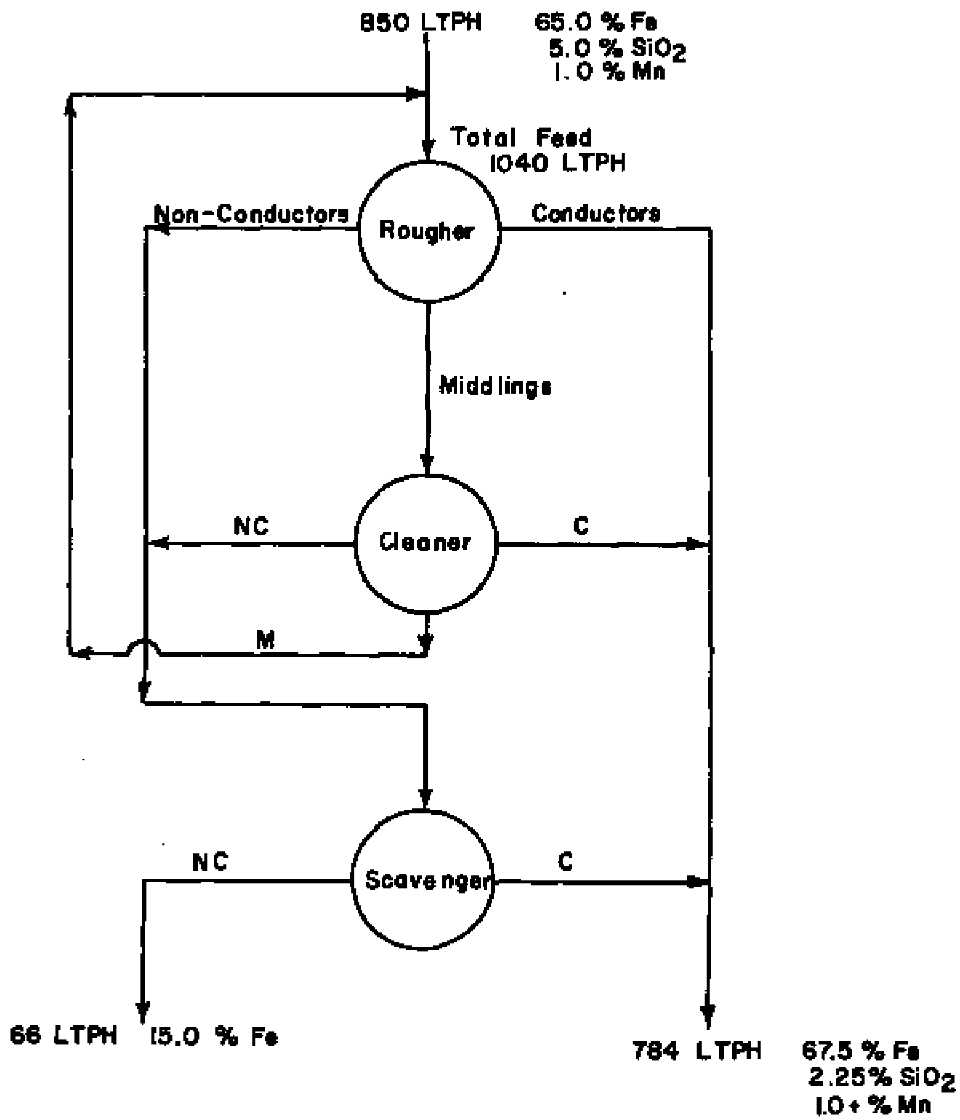

Figure 10.14. Wabush high-tension flowsheet.

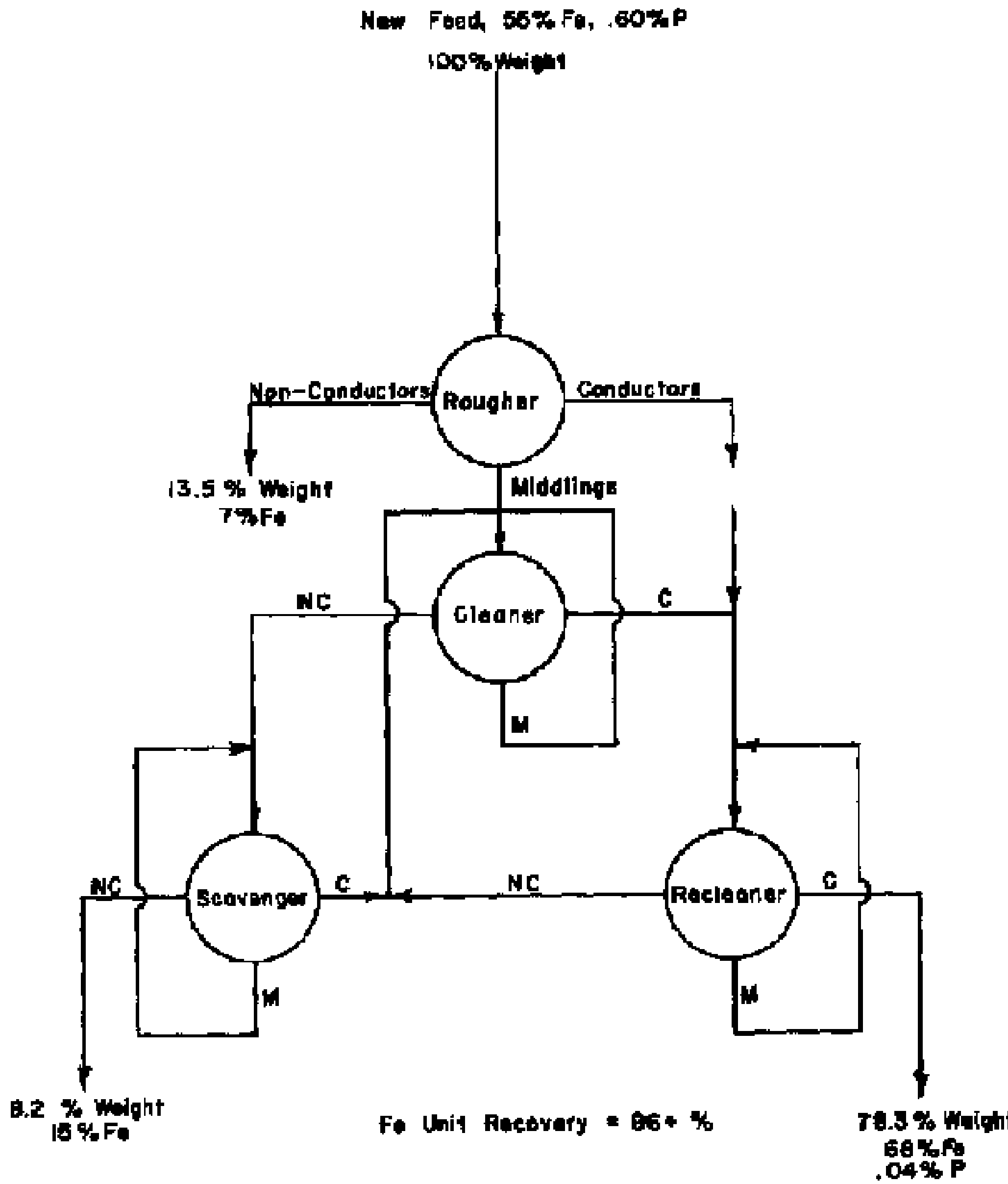

Figure 10.15. Swedish LKAB high-tension flowsheet.

- Heavy Minerals - Heavier than Quartz in beaches, dunes and streams.
- Sluices or Humphrey Stn. – wet gravity concentrate
- Iron ore Concentration Beneficial of Iron ore
- Crushed- to about – 0.6 mm
- Concentrated wet by gravity – dried
- Gravity – initially Wabush- 6 million tons per year. ES later
- 1000+ tons/hr – $ 1.7 million US(1971)
- Conveyance-35% - belt
- 25%- belt+buckets
- $0.04/ton- operating labor
- LKAB – Sweden – Heamatite
- 1 million tons/yr – crushed /ground dry-with heat.H.T