Liquids Streaming Current

The streaming current, I_s, is due to the charge density and velocity of the fluid over the double layer.

$$I_s = \left[\frac{10\,x10^{-6}\ amp}{(m/s)^2\,(m)^2} \right] (u\,d)^2 \left[1 - \exp\left(-\frac{L}{u\,\tau} \right) \right]$$

$$\tau = \frac{\varepsilon_r\,\varepsilon_0}{\gamma_c} \qquad \varepsilon_0 = 8.85\,x10^{-12}\,\frac{coulomb^2}{N\,m^2} = 8.85\,x10^{-14}\,\frac{s}{ohm\ cm}$$

See table 7-2 (page 314)

Table 7-2 Properties for Electrostatic Calculations[1]

Material	Specific conductivity[2] (mho/cm)	Dielectric constant
Liquids		
Benzene	7.6×10^{-8} to $<1 \times 10^{-18}$	2.3
Toluene	$<1 \times 10^{-14}$	2.4
Xylene	$<1 \times 10^{-15}$	2.4
Heptane	$<1 \times 10^{-18}$	2.0
Hexane	$<1 \times 10^{-18}$	1.9
Methanol	4.4×10^{-7}	33.7
Ethanol	1.5×10^{-7}	25.7
Isopropanol	3.5×10^{-6}	25.0
Water	5.5×10^{-6}	80.4

Solids Streaming Current

Charging of solids depends on type of operation such as sieving, pouring, grinding, micronizing, sliding down an incline, or transport.

See Table 7-3 (page 315)

$$I_S = \left(\frac{coulombs}{kg}\right)\left(\frac{kg}{s}\right) = (charge)(flowrate)$$

Table 7-3 Charge Buildup for Various Operations[1]

Process	Charge (coulomb/kg)
Sieving	10^{-9} to 10^{-11}
Pouring	10^{-7} to 10^{-9}
Grinding	10^{-6} to 10^{-7}
Micronizing	10^{-4} to 10^{-7}
Sliding down an incline	10^{-5} to 10^{-7}
Pneumatic transport of solids	10^{-5} to 10^{-7}

[1] R. A. Mancini, "The Use (and Misuse) of Bonding for Control of Static Ignition Hazards," *Plant/Operations Progress* (Jan. 1988) 7(1): 24.

Table 7-4 Accepted Electrostatic Values for Calculations[1]

Voltage to produce spark between needle points 1/2 in apart	14,000 V
Voltage to produce spark between plates 0.01 mm apart	350 V
Maximum charge density before corona discharge	2.65×10^{-9} coulomb/cm^2
Minimum ignition energies (mJ)	
Vapors in air	0.1
Mists in air	1.0
Dusts in air	10.0
Approximate capacitances *C* (micro-microfarads)	
Humans	100 to 400
Automobiles	500
Tank truck (2000 gal)	1000
Tank (12-ft diameter with insulation)	100,000
Capacitance between two 2-in flanges (1/8-in gap)	20
Contact zeta potentials	0.01–0.1 V

[1]F. G. Eichel, "Electrostatics," *Chemical Engineering* (March 13, 1967), p. 163.

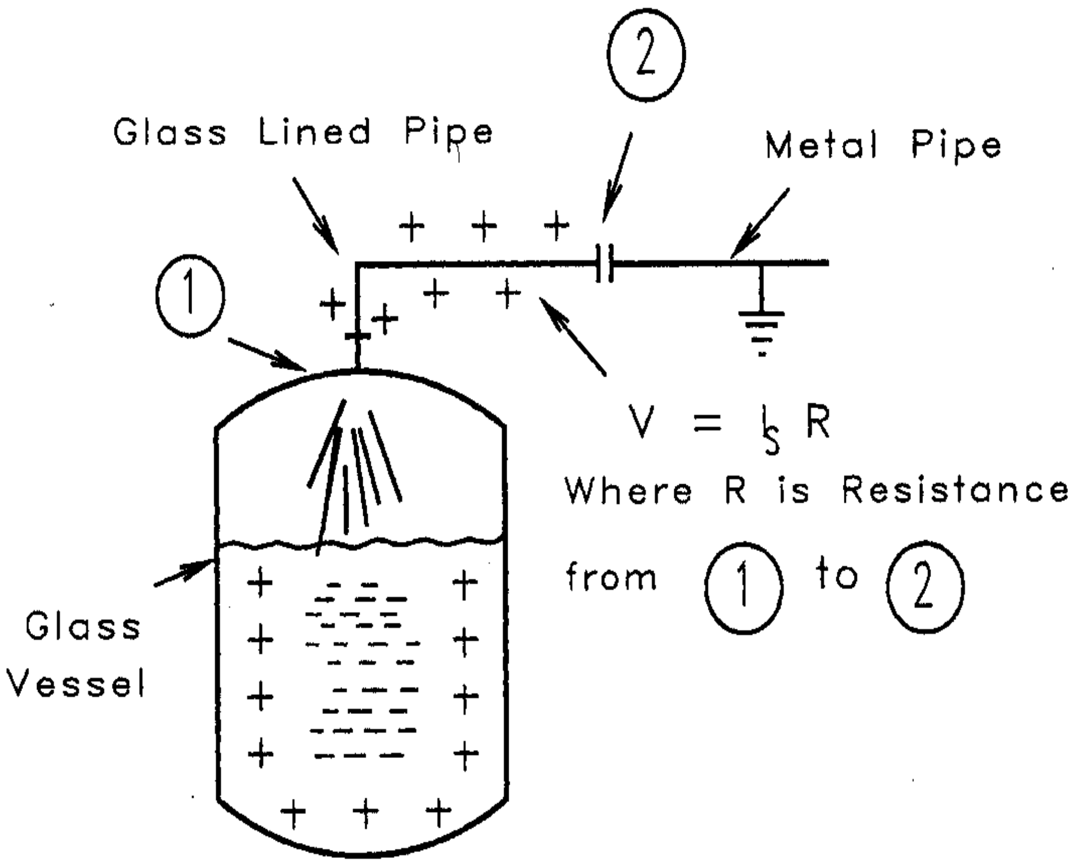
Charge on a Streaming Current

Charges can accumulate as a result of a streaming current $dQ/dt = I_s$. Assuming a constant streaming current,

$$Q = I_s t$$

This equation assumes that the system starts with no accumulation of charge, only one constant source of charge I_s and no current or charge loss term.

Electrostatic Voltage Drops



$$V = I_S R$$

$$R = \frac{L}{\gamma_c A}$$

$$\text{units} = \frac{\text{ohm}}{\text{L/A}} \cdot \frac{\text{L}}{\text{A}} = \text{ohm}$$

Energy of Charged Capacitors

Capacitance = C = Q/V

Voltage of a capacitor: V = Q/C

Work to a charged capacitor

C: [farads]

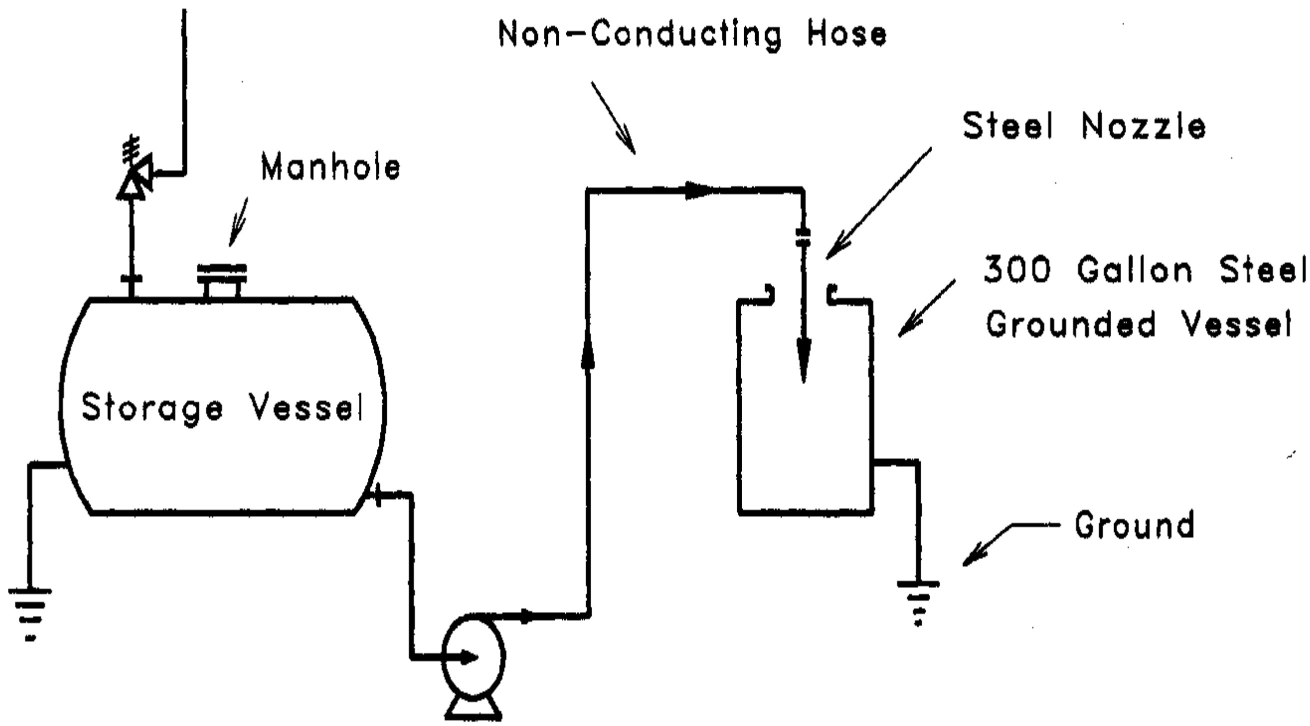
V: [volts]

Q: [coulombs]

$$\int dJ = \int V\,dQ = \int \frac{Q}{C}dQ$$

$$J = \frac{Q^2}{2C} = \frac{CV^2}{2} = \frac{QV}{2}$$

Example 7-4



- Flow rate of 1gpm, the energy charged at nozzle 5.49×10^{-14}J
  the energy charged at tank 0.99mJ
- Flow rate of 150gpm, the energy charged at nozzle 117J
  the energy charged at tank 8.45×10^{7}J

Capacitance of a Body

- **Parallel flat**

$$V = \frac{QL}{\varepsilon_r \varepsilon_0 A} \qquad C = \frac{\varepsilon_r \varepsilon_0 A}{L}$$

- **Spherical**

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{\varepsilon_r r} \qquad C = 4\pi\varepsilon_r\varepsilon_0 r$$

See examples 7-5, 7-6, 7-7

Balance of Charges

For systems with several inlet lines and several outlet lines

$$\frac{dQ}{dt} = \sum^{n} \left(I_s \right)_{i,in} - \sum^{m} \left(I_s \right)_{j,out} - \frac{Q}{\tau}$$

$$\frac{dQ}{dt} = \sum^{n} \left(I_s \right)_{i,in} - \sum^{m} \frac{F_j}{V_c} Q - \frac{Q}{\tau}$$

Balance of Charges – Special Cases

Case: The flows, streaming currents, and relaxation time are constant

$$Q = A + Be^{-C}t$$

This equation is useful when the filling and discharging rates are sequential.

Case: Filling a tank (one inlet, no outlet)

$$Q = I_s\tau + \left(Q_0 - I_s\tau\right)e^{-t/\tau}$$

Example 7-9

- **Charge buildup with toluene vessel**
  - **J when the vessel fluid just reaches the overflow line; J=9.55mJ**
  - **J under equilibrium; 4.22mJ**
  - **Half time of equilibrium charge without inlet charge; 14.7 s**
- **Charge Dissipation**
  - **Charge loss by relaxation 1.86×10^{-8} C/s**
  - **Charge loss by the overflow 1.31×10^{-7} C/s**

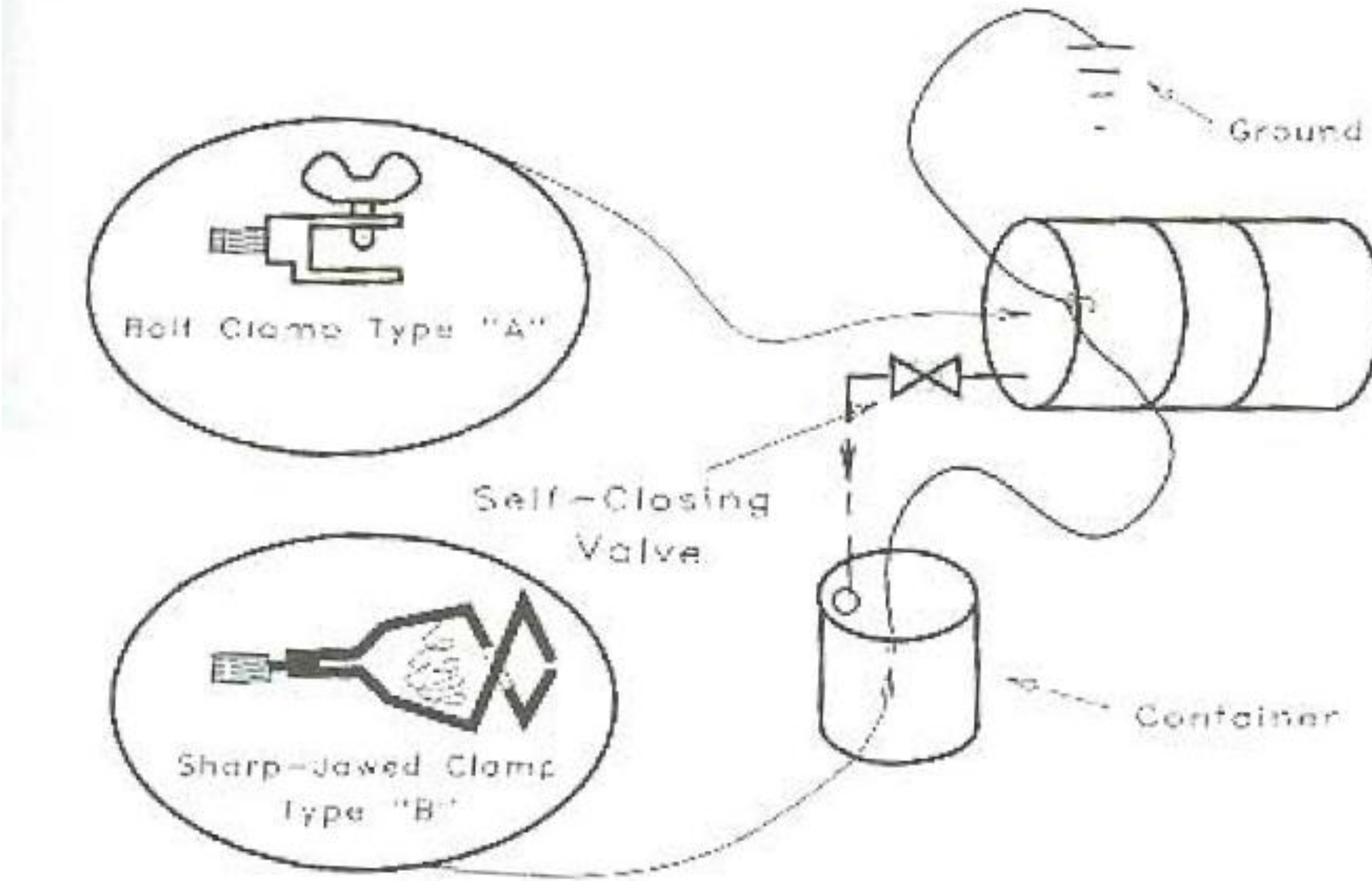
Scenario for explosion

- Mixture within flammability range
- Charges have accumulated: > 350 V
- Discharge energy > MIE Energies > 0.1 mJ hazards

Preventive measures: must control all three factors

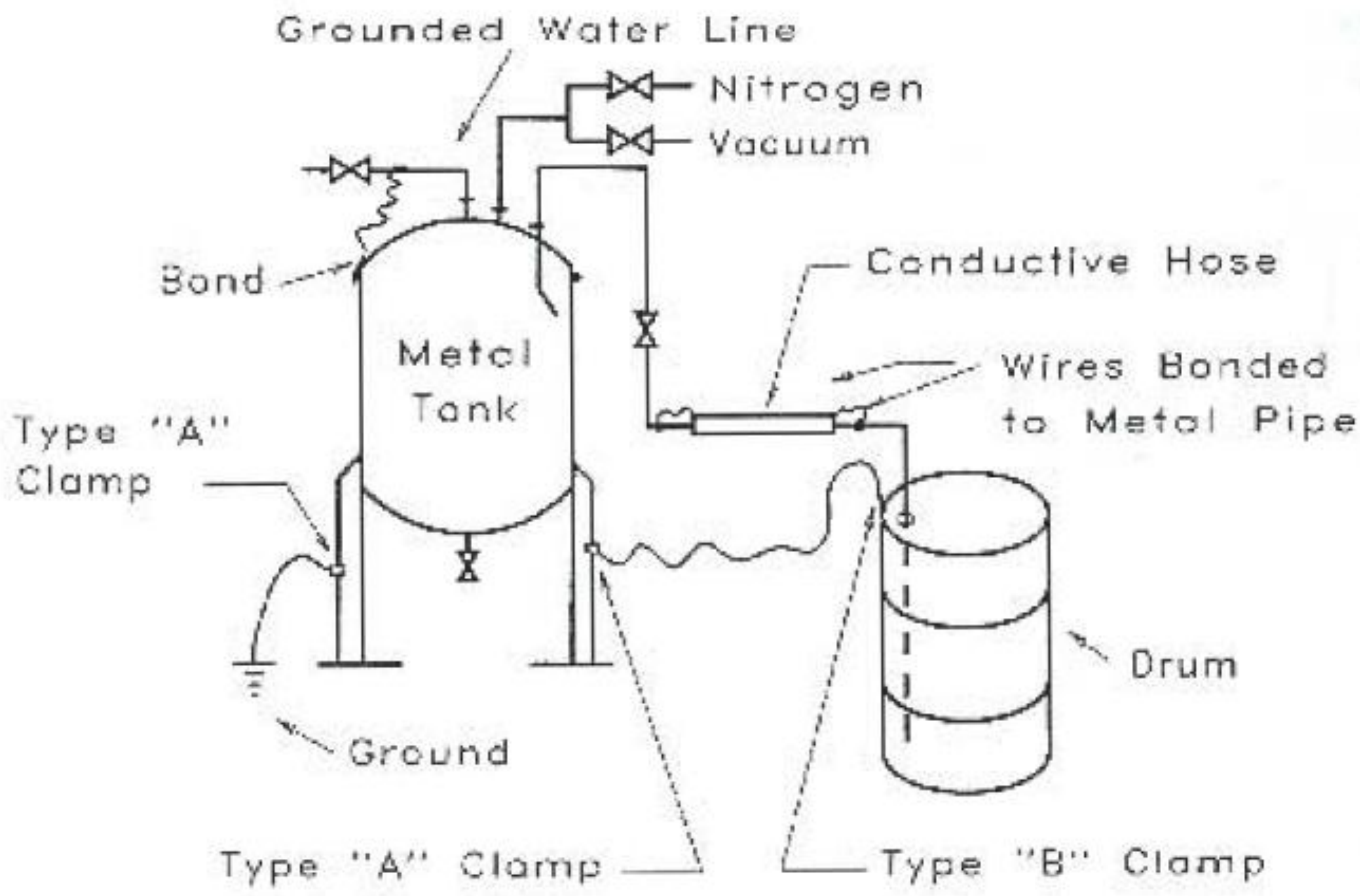
Controlling Static Electricity I

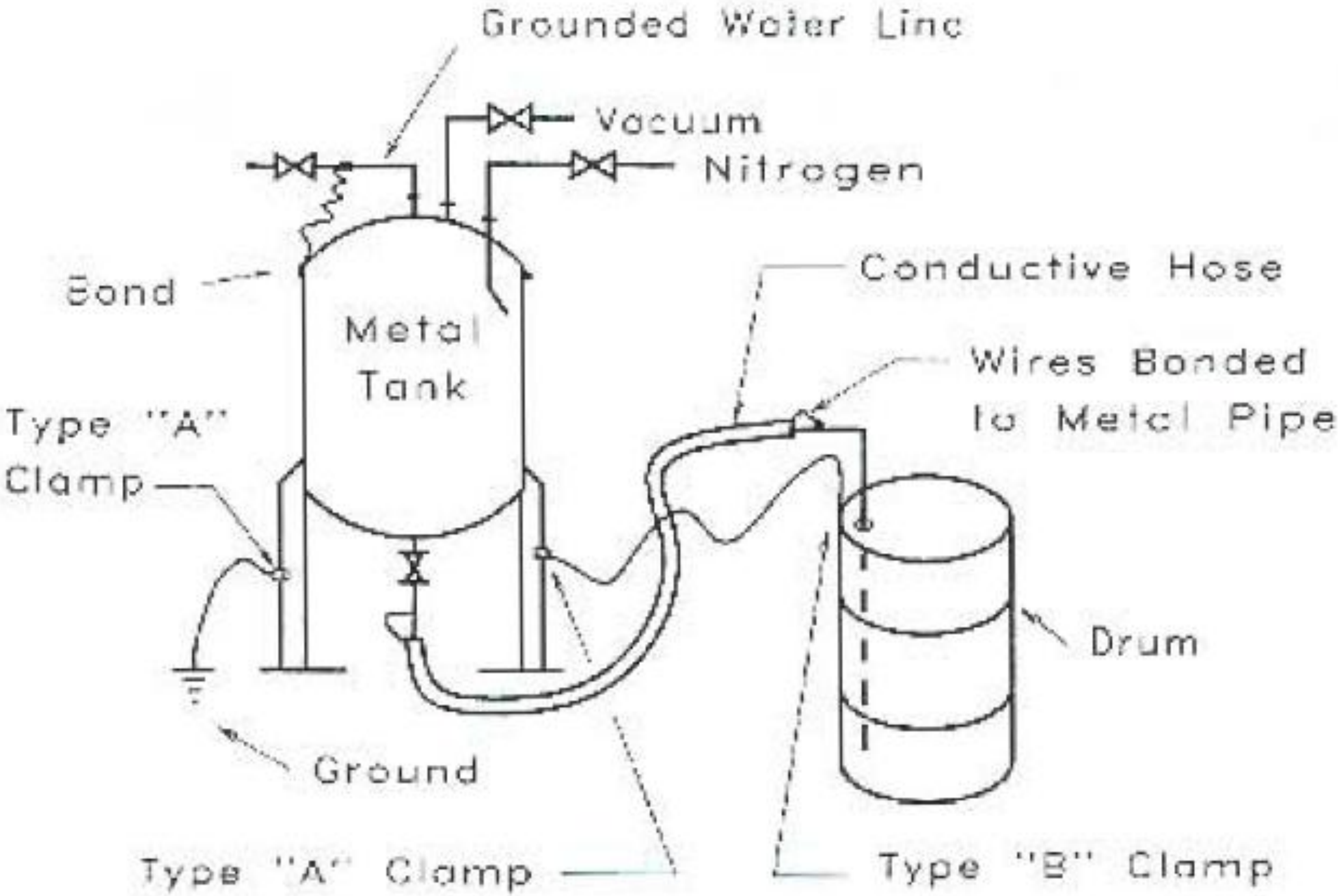
- **General Design Methods (Prevent charge from accumulating to dangerous level by)**
  - **Reducing the rate of charge generation (liquids)**
  - **Increasing the rate of charge relaxation (liquids)**
  - **Low-energy discharge design (powders)**
- **General Design Methods (Preventing the possibility of an ignition by)**
  - **Maintaining oxidant level below the combustible level**
  - **Maintaining fuel level <LFL, or >UFL**

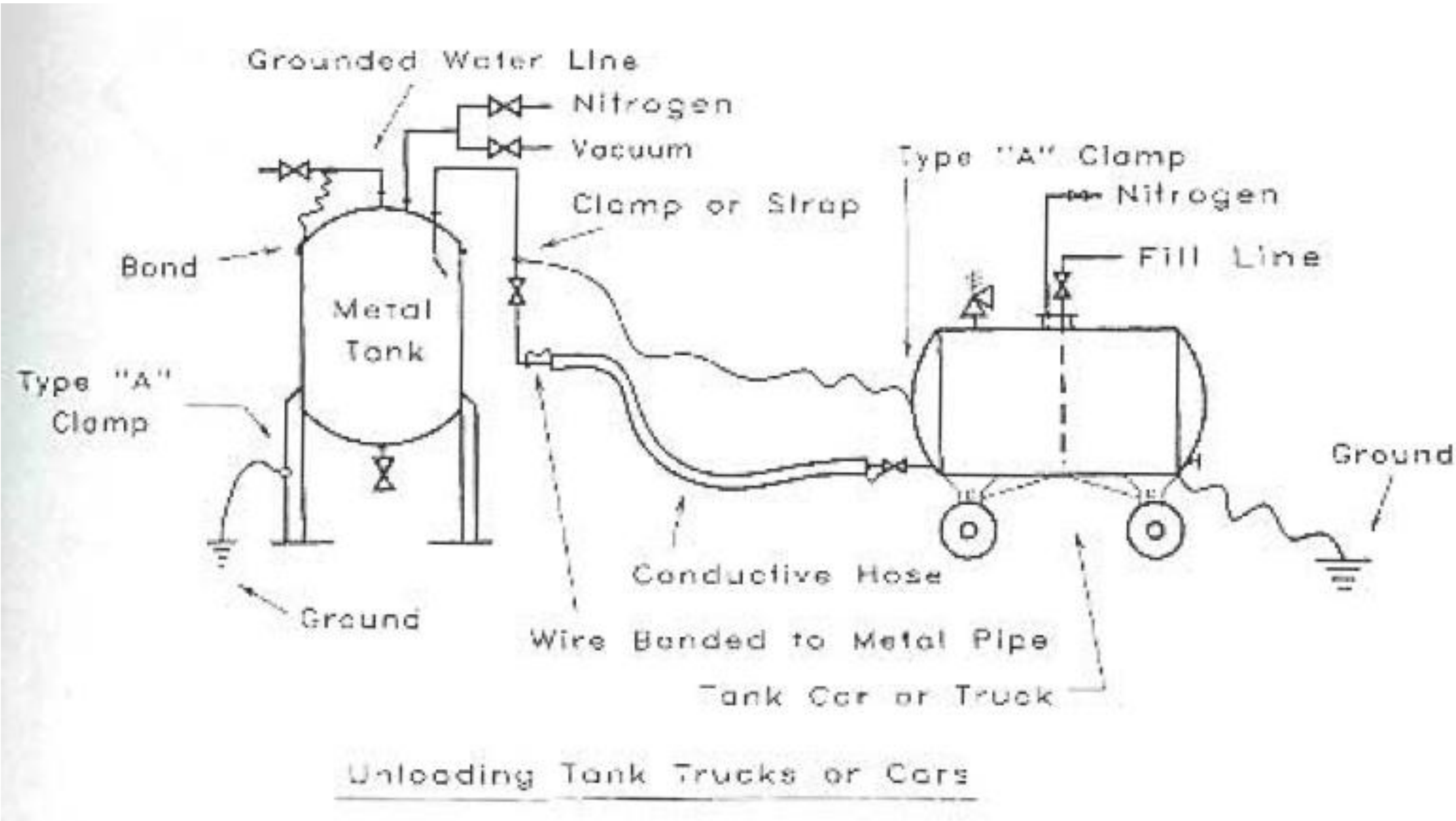

Ground
Bolt Clamp Type "A"
Self-Closing
Valve
Container
Sharp-Jawed Clamp
Type "B"

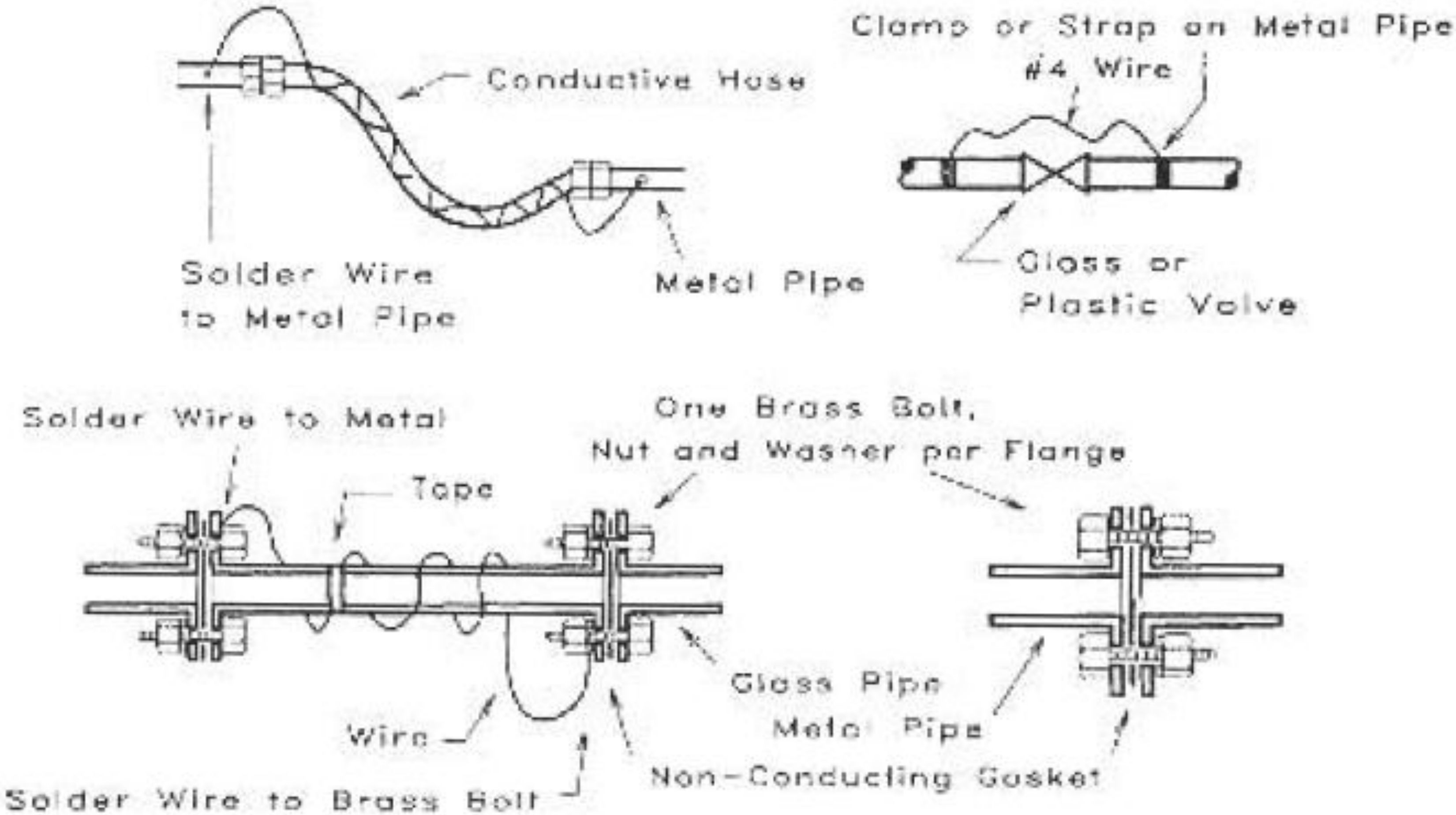
Controlling Static Electricity II

- Relaxation
  - Enlarged section of pipe at entrance
- Bonging & Grounding
  - Fig. 7-18, 7-19, 7-20, pp 333~336
- Dip Pipes
  - Fig. 7-21, p. 336
- Additives
  - Increasing conductivity
- Handling Solids
  - Fig. 7-22, 7-23, p. 337, p.338


Grounded Water Line
Nitrogen
Vacuum
Bond
Metal
Tank
Conductive Hose
Wires Bonded
to Metal Pipe
Type "A"
Clamp
Drum
Ground
Type "A" Clamp
Type "B" Clamp


Grounded Water Line
Vacuum
Nitrogen
Bond
Metal Tank
Conductive Hose
Wires Bonded to Metal Pipe
Type "A" Clamp
Drum
Ground
Type "A" Clamp
Type "B" Clamp


Grounded Water Line
Nitrogen
Vacuum
Type "A" Clamp
Nitrogen
Clamp or Strap
Fill Line
Bond
Metal Tank
Type "A" Clamp
Ground
Conductive Hose
Ground
Wire Bonded to Metal Pipe
Tank Car or Truck
Unloading Tank Trucks or Cars


Conductive Hose
Solder Wire
to Metal Pipe
Metal Pipe
Clamp or Strap on Metal Pipe
#4 Wire
Glass or
Plastic Valve
Solder Wire to Metal
One Brass Bolt,
Nut and Washer per Flange
Tape
Glass Pipe
Metal Pipe
Wire
Non-Conducting Gasket
Solder Wire to Brass Bolt

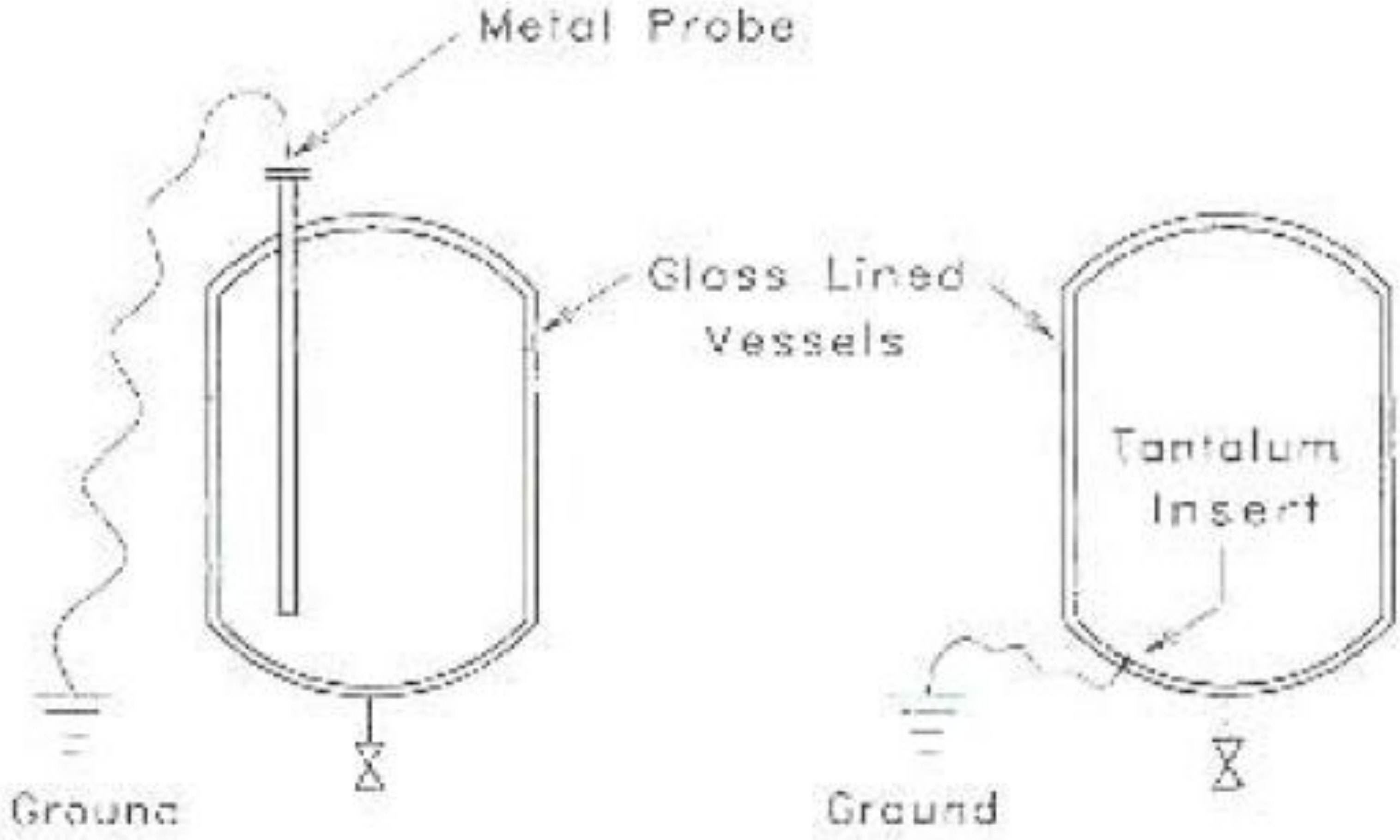


Figure 7-20 Grounding glass-lined vessels.

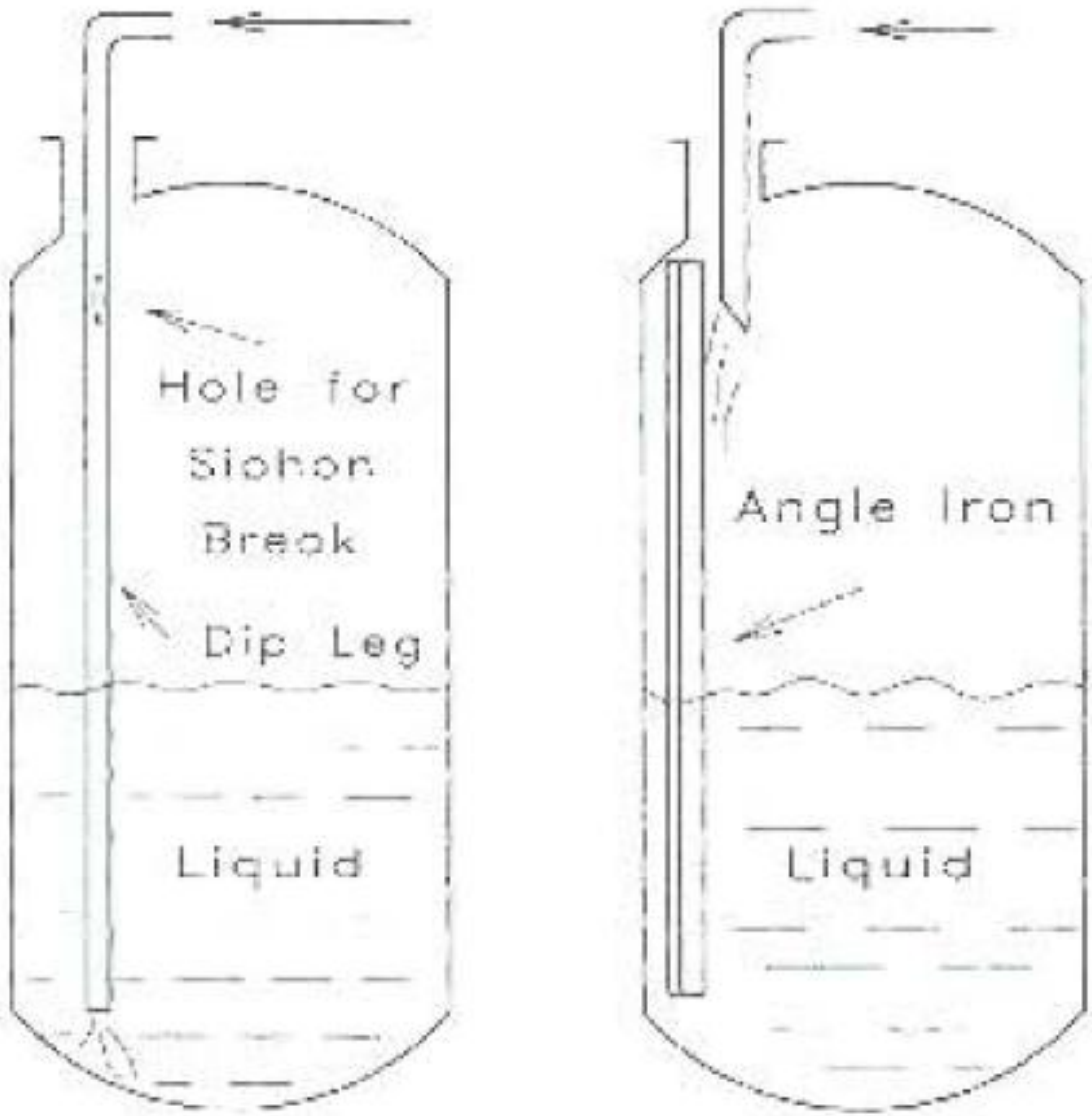
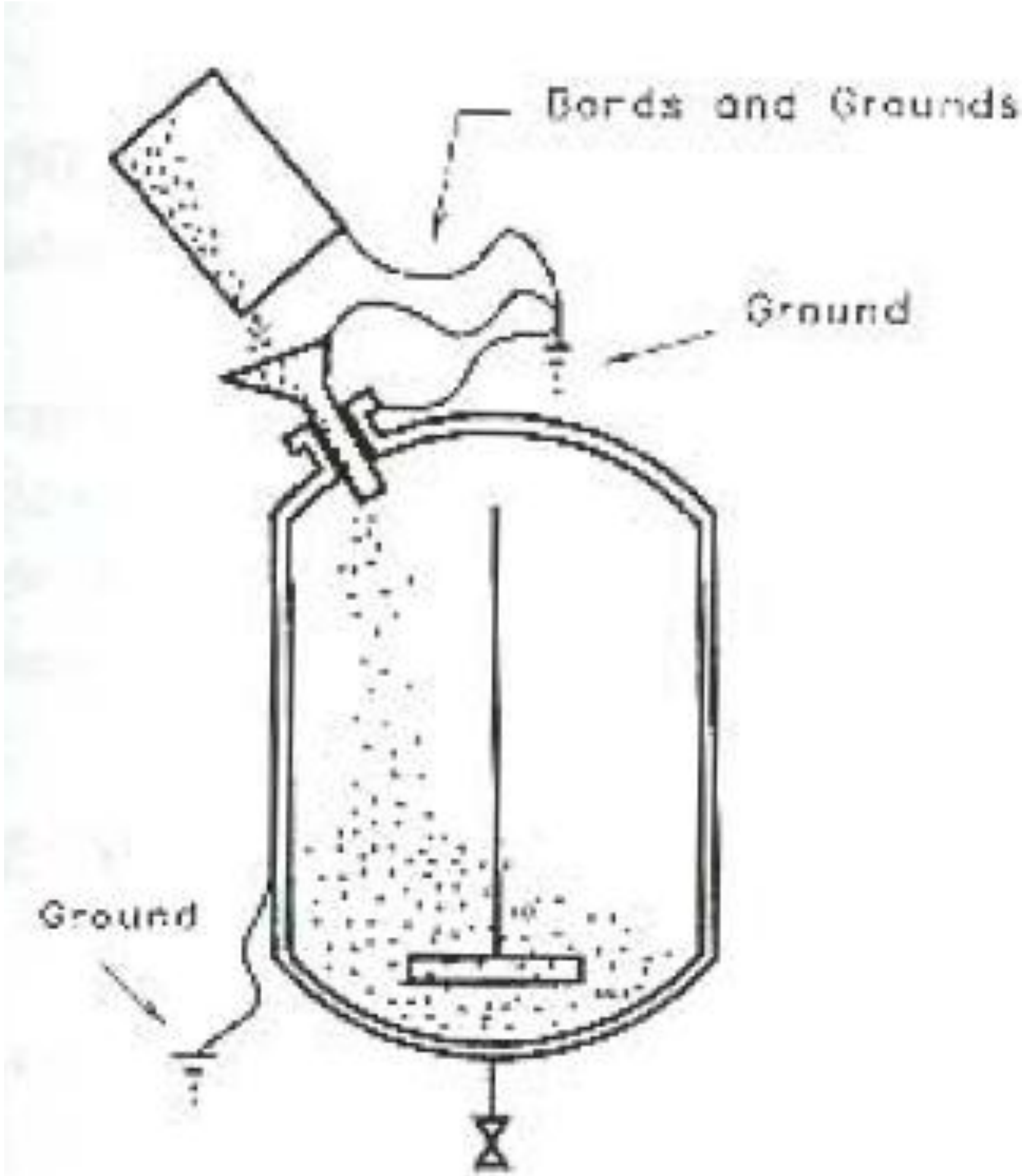
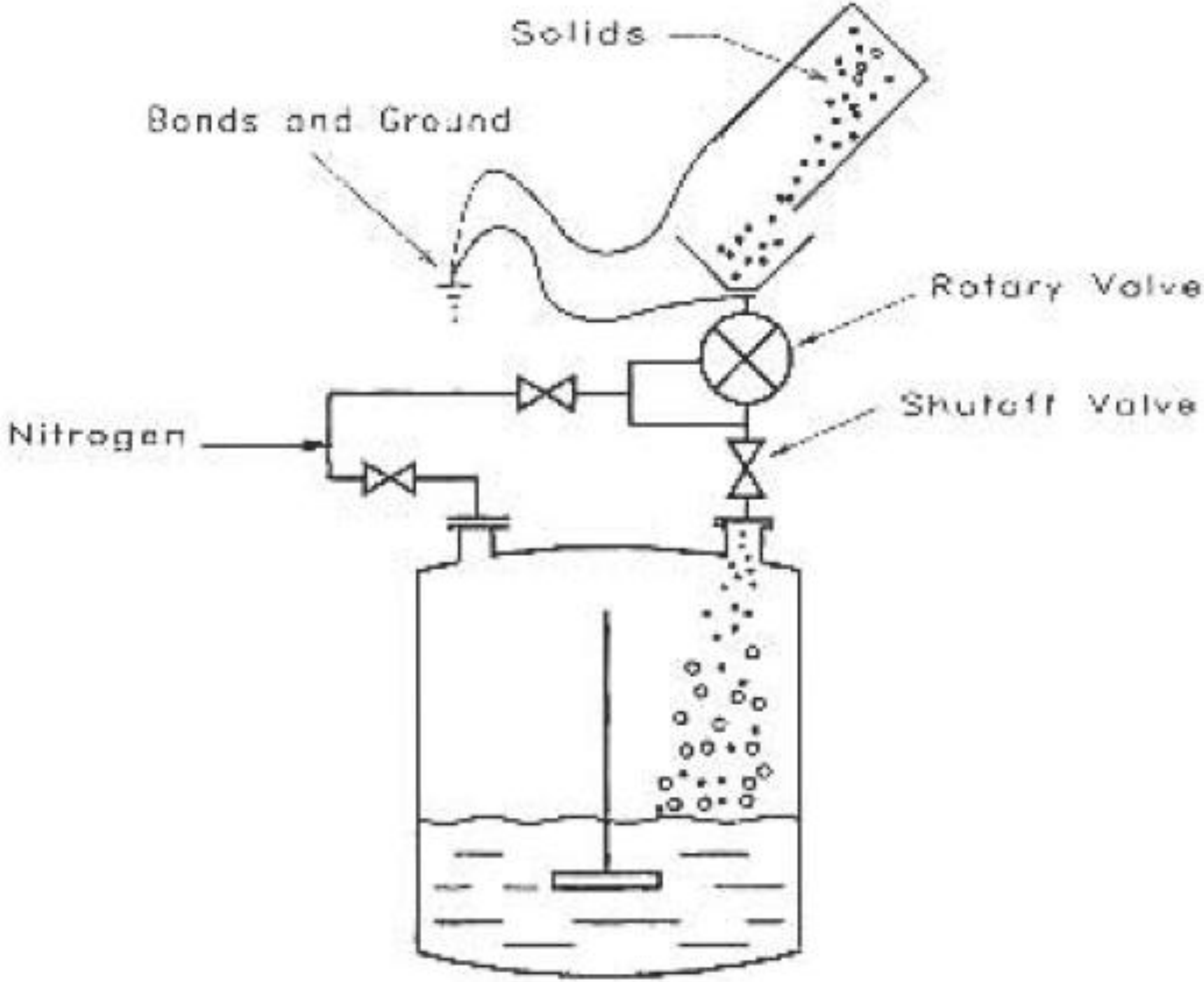
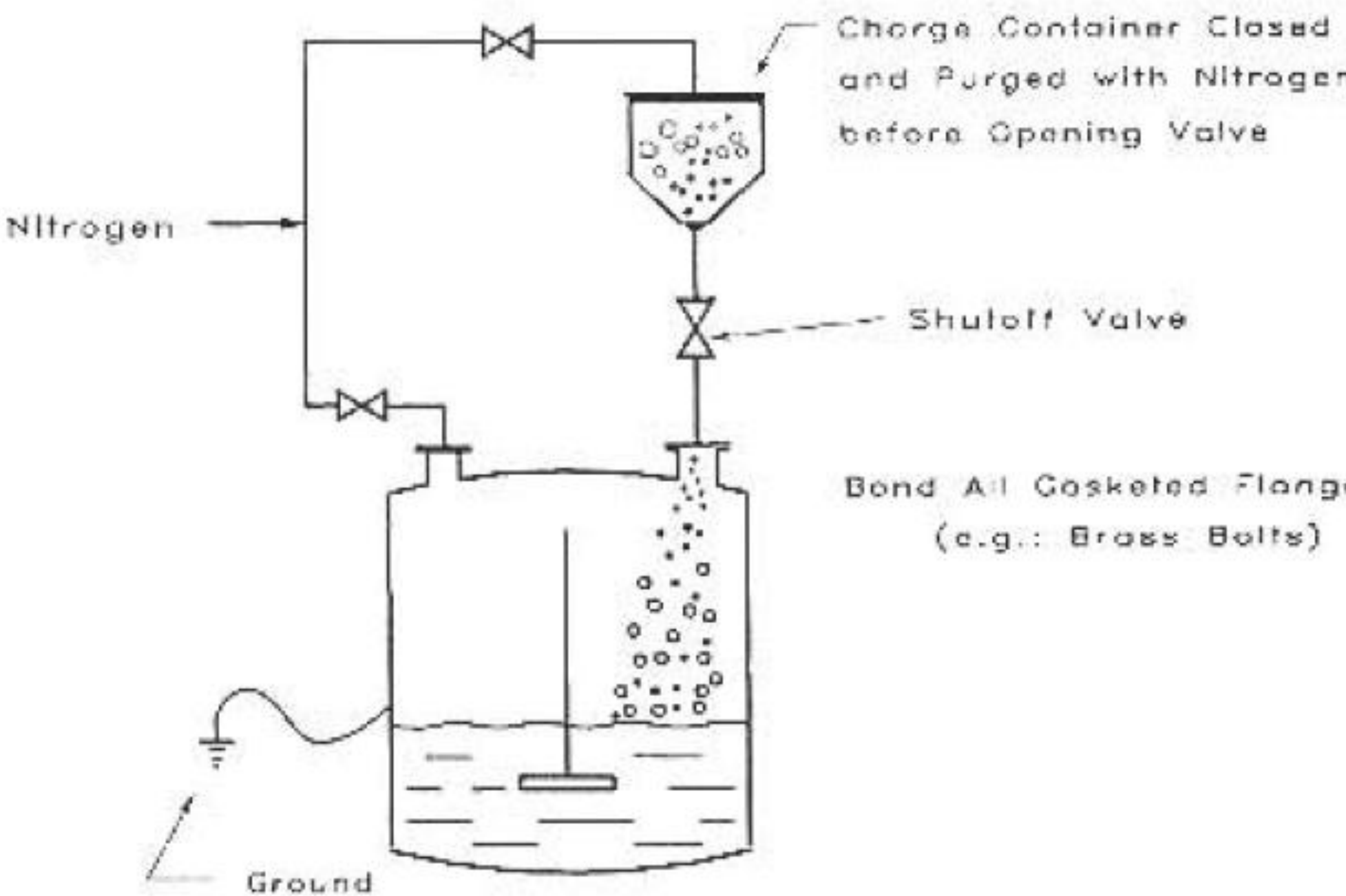


Figure 7-21 Dip legs to prevent free fall and accumulation of static charge.


Bonds and Grounds
Ground
Ground


Solids
Bonds and Ground
Rotary Valve
Shutoff Valve
Nitrogen


Charge Container Closed
and Purged with Nitrogen
before Opening Valve
Nitrogen
Shutoff Valve
Bond All Gasketed Flanges
(e.g.: Brass Bolts)
Ground

Controlling Static Electricity III

- XP (Explosion-proof) Housing
  - Ex. Motor starter
- Classification of Area
  - Class I: Flammable gas or vapor
  - Class Ii: Same for combustible dust
  - Class III: Combustible fibers or dusts, not likely to be in suspension
- Classification of Materials
  - Group A~G
- Ventilation & Sprinkler System

Home assignment, due on Fri), Text 7-4, 5, 11, 13, 25