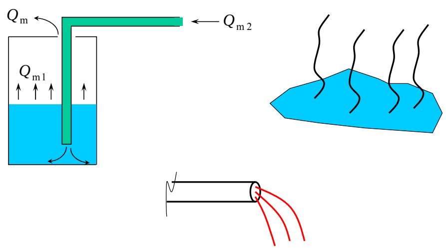
Chapter 4: Source Models



Source Models

- What: Describe how material escapes from a process
- Why: Required to determine potential consequences of and accident

Risk = f(Probability, Consequences)

What do Source Models Provide?

- Release rate, mass/time
- Total amount released
- State of material: liquid, solid, gas, combination

Why do we need Source Models?

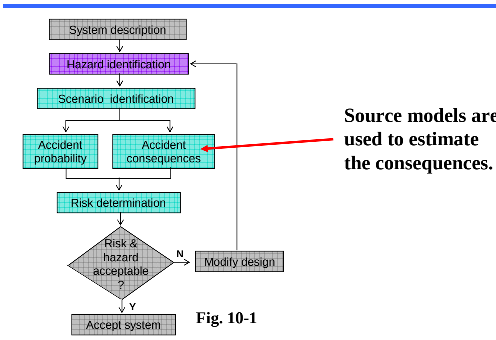
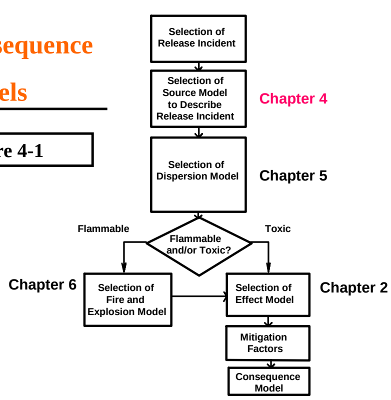


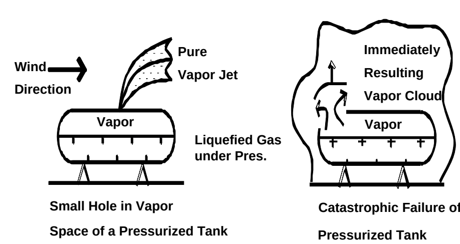
Fig. 10-1

Consequence Models

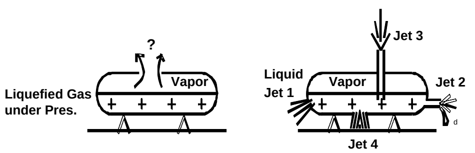
Figure 4-1



Release Mechanisms - 1



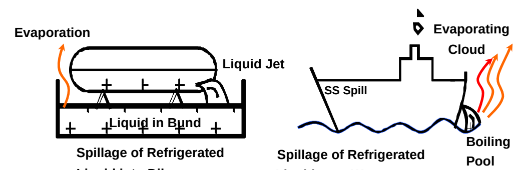
Release Mechanisms - 2



Intermediate Hole in Vapor Space of a Pressurized Tank

Escape of Liquefied Gas from a Pressurized Tank

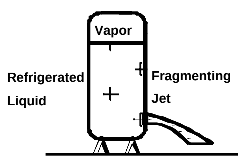
Release Mechanisms - 3



Spillage of Refrigerated Liquid into Dike

Spillage of Refrigerated Liquid onto Water

Release Mechanisms - 4



High-Velocity Fragmenting Jet from Refrigerated Containment Vessel

Infinitely more possibilities!

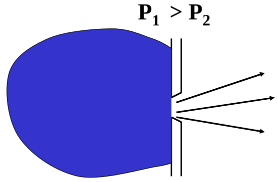
Release Mechanism Parameters

Nature of release depends on lots of parameters:

1. **Temperature and pressure of released material.**
2. **Composition of released material.**
3. **Ambient temperature and pressure.**
4. **Ambient wind, humidity**
5. **Geometry of release (hole, rupture, catastrophic failure)**
6. **Vapor – Liquid – Equilibrium of released material.**
7. **Velocity of release.**
8. **Many others!**

Source Model: Liquid thru a hole

$P_1 > P_2$



1. Pressure drives liquid thru hole
2. Pressure energy converted to KE as liquid escapes
3. Frictional losses

Mechanical Energy Balance for Incompressible flow

$$\boxed{\frac{\Delta P}{\rho} + \frac{\Delta \bar{u}^2}{2 g_c} + \frac{g}{g_c}\Delta z + F = -\frac{W_s}{\dot{m}}} \qquad \text{Eq. 4-28}$$

P = Pressure
ρ = Density
$\bar{u}$ = Velocity
g_c = Gravitational Constant
g = Acceleration due to gravity
z = Height above datum
F = Friction
W_s = Shaft work
$\dot{m}$ = Mass flow

$$\frac{\Delta P}{\rho} + \frac{\Delta \bar{u}^2}{2g_c} + \frac{g}{g_c}\Delta z + F = -\frac{W_s}{\dot{m}}$$

$\frac{\Delta P}{\rho}$ = Pressure energy

$\frac{\Delta \bar{u}^2}{2g_c}$ = Kinetic Energy

$\frac{g}{g_c}\Delta z$ = Potential Energy

F = Frictional losses

$-\frac{W_s}{\dot{m}}$ = Mechanical Energy from pumps / turbines

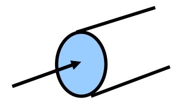
Make Assumptions for Hole:

Horizontal: $\Delta z \approx 0$

No Pumps / turbines: $W_s = 0$

$F \neq 0$

Solve ME balance for u



Apply: $Q_m = \rho u A$

$$Q_m = \left(\frac{\text{kg}}{\text{m}^3}\right)\left(\frac{\text{m}}{\text{s}}\right)\left(\text{m}^2\right) = \text{kg/s}$$

Orifice Discharge Equation

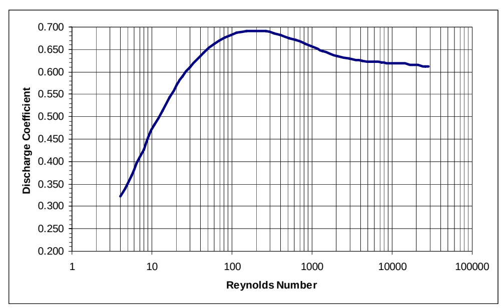
$$\boxed{Q_m = C_o A \sqrt{2 \rho g_c \Delta P}} \qquad \text{Eq. 4-7}$$

C_o= Discharge coefficient accounts for friction

= 1 ---> no friction

= 0.61 for turbulent flow of liquids.

Orifice Discharge Coefficient



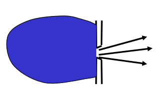
See Perry's for more details!

Example

1-inch diameter hole

100 psig upstream pressure

Water



$$A = \frac{\pi D^2}{4} = \frac{(3.14)\left[(1\text{ in})\left(\frac{1\text{ ft}}{12\text{ in}}\right)\right]^2}{4} = 5.45\times10^{-3}\,\text{ft}^2$$

$C_o = 0.61$ for highly turbulent flow

$\Delta P = 100$ psig $- 0$ psig $= 100$ psi$= 100$ lb$_f$/in^2

Substitute in Orifice Equation

$$Q_m = C_o A \sqrt{2 \rho g_c \Delta P}$$

$$Q_m = (0.61)\left(5.45\times10^{-3}\ \text{ft}^2\right)$$

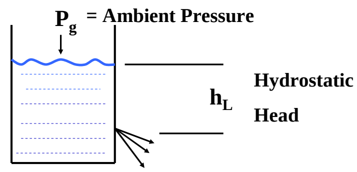
$$\times\sqrt{(2)\left(62.4\frac{\text{lb}_m}{\text{ft}^3}\right)\left(32.17\frac{\text{ft-lb}_m}{\text{lb}_f - \text{s}^2}\right)\left(100\frac{\text{lb}_f}{\text{in}^2}\right)\left(\frac{144\ \text{in}^2}{\text{ft}^2}\right)}$$

$$Q_m = 25.3\ \text{lb}_m/\text{s}$$

This is 3.03 gallons/sec.

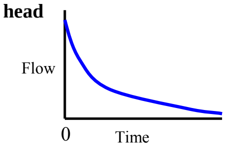
The discharge velocity is 74 ft/sec!

Hole in a Tank



Pressure at hole due to hydrostatic head plus ambient pressure.

Flow is maximum at t = 0 and decreases with time.



$$Q_m = \rho A C_o \sqrt{2\left(\frac{g_c P_g}{\rho} + g h_L\right)}$$ **Eq. 4-12**

Q_m = Mass flow rate
ρ = Liquid density
A = Hole area
C_o = Discharge coefficient
g_c = Gravitational constant
P_g = Gauge pressure in vapor space
g = Acc. due to gravity
h_L = Liquid height above hole.

Hole in a Tank

$$\frac{dm}{dt} = \rho \frac{dV}{dt} = -Q_m$$ **Mass balance: Accumulation = -Output**

For a cylindrical vessel, $V = A_t h_L$ and it follows that:

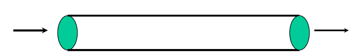
$$\rho A_t \frac{dh_L}{dt} = -Q_m(h_L)$$

Can solve above equations to determine:

1. **Total draining time.**
2. **Liquid level as a function of time.**
3. **Discharge rate as a function of time.**

See textbook for details.

Liquid Flow Thru Pipes



P_1 > P_2

- **Pressure is driving force**
- **Velocity is constant if pipe diameter constant**
- **Pressure drops due to friction**

Mechanical Energy Balance for Pipe Flow

$$\frac{\Delta P}{\rho} + \frac{\Delta u^2}{2 g_c} + \frac{g}{g_c}\Delta z + F = -\frac{W_s}{\dot{m}}$$

$\frac{\Delta P}{\rho}$ = Pressure Energy

$\frac{\Delta u^2}{2 g_c}$ = Kinetic Energy (KE)

$\frac{g}{g_c}\Delta z$ = Potential Energy (PE)

F = Frictional Losses

$-W_s / \dot{m}$ = Shaft Work from Mechanical Linkage

Frictional Losses for Pipe Flow - 1

$$F = K_f \left(\frac{\bar{u}^2}{2 g_c}\right)$$

where K_f is the excess head loss

$\left(\frac{\bar{u}^2}{2 g_c}\right)$ is the velocity head

For pipe lengths: $K_f = \frac{4 f L}{d}$

where f is the Fanning friction factor (see text for computing)

L is the pipe length

d is the pipe diameter

Fanning Friction Factor

Friction term, *F*, given by:

$$F = \frac{2 fLu^2}{g_c d}$$

L = Pipe Length, g_c = grav. constant
u = Liquid ave. velocity, d = Pipe diam.

***f* = Fanning friction factor**

= f(Reynolds no., pipe roughness)

Equations (4-31 to 4-37) and Figure (4-7) provided in textbook for *f*.

Differs from Moody friction factor!

Frictional Losses for Pipe Flow -2

For pipe fittings:

$$K_f = \frac{K_1}{\mathrm{Re}} + K_\infty\left(1 + \frac{1}{ID_{inches}}\right)$$

where K_1 and K_∞ are constants (see Table 4-2)

Re is the Reynolds number

ID_{inches} is the fitting diameter in inches

K_1 important at low Re while K_∞ important at high Re.

Example – Horizontal Pipe, no fittings

$KE \approx 0 \rightarrow u = \text{constant} \rightarrow \Delta u^2 = 0$

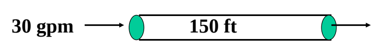
$\Delta z \approx 0$ since horizontal

$W_s \approx 0$ since no pumps or turbines

$$\boxed{\frac{\Delta P}{\rho} = -F = -\frac{2 fLu^2}{g_c d}}$$

Example:

What is pressure drop across 150 ft of 1-inch Sch. 40, commercial steel pipe if flow = 30 gpm? Viscosity = 1.0 cp (water), cp = centipoise



Procedure:

1. Convert to appropriate units

2. Select equation

3. Determine Reynolds number and then *f*

4. Calculate answer.

1. Convert to Appropriate Units

I.D. = 1.049" = 0.0874 ft = 26.6 mm

$$A = \frac{\pi D^2}{4} = \frac{(3.14)(0.0874\ \text{ft})^2}{4} = 0.0060\ \text{ft}^2$$

$$Q_v = (30\ \text{gal/min})\left(\frac{0.1337\ \text{ft}^3}{1\ \text{gal}}\right) = 4.011\ \text{ft}^3/\text{min}$$

$$u = \frac{Q_v}{A} = \frac{4.011\ \text{ft}^3/\text{min}}{0.0060\ \text{ft}^2} = 668\ \text{ft/min} = 11.1\ \text{ft/sec}$$

Note: Typical pipe liquid velocity about 10 ft/sec.

2. Select Equation:

Mechanical Energy Balance:

No Pumps: $W_s = 0$

Horizontal: $\Delta z = 0$

Velocity constant: $\Delta u^2 = 0$

$$\boxed{\frac{\Delta P}{\rho} = -F = -\frac{2 fLu^2}{g_c d}}$$

3. Determine Reynolds No. and then Friction Factor

$$\mathrm{Re} = \frac{Du\rho}{\mu} \qquad D = \text{ diam., } u = \text{velocity,}$$

$\rho = \text{density, } \mu = \text{viscosity}$

$1 \text{ cp} = 6.72 \times 10^{-4} \text{ lb}_m / \text{ft-sec}$

$$\mathrm{Re} = \frac{(0.0874 \text{ ft})(11.1 \text{ ft/sec})(62.4 \text{ lb}_m / \text{ft}^{3})}{6.72 \times 10^{-4} \text{ lb}_m / \text{ft-sec}}$$

$\mathrm{Re} = 9.01 \times 10^{4}$ (no units!)

3. Determine Reynolds No. and then Friction Factor

From Table 4-1, $\varepsilon = 0.046$ mm (pipe roughness)

Then

$$\left(\frac{\varepsilon}{d}\right) = \frac{0.046 \text{ mm}}{26.6 \text{ mm}} = 0.00173$$

From Figure 4-7 (or equations in text), $f = 0.00616$

4. Calculate Answer:

$$\frac{\Delta P}{\rho} = -F = -\frac{2fLu^2}{g_c d}$$

$$\Delta P = \frac{-(2)(0.00616)(150 \text{ ft})(11.1 \text{ ft/s})^2 (62.4 \frac{\text{lb}_m}{\text{ft}^3})}{(32.17 \frac{\text{ft lb}_m}{\text{lb}_f \text{ s}^2})(0.0874 \text{ ft})}$$

$\Delta P = -5052 \text{ lb}_f / \text{ft}^2 = -35.1 \text{ lb}_f / \text{in}^2$ (psi)

General Pipe Flow Problem

For the general case, with fittings, changes in elevation, pumps, etc., problem is by trial and error.

Procedure:

1. **Guess velocity**
2. **Compute Reynolds Number**
3. **Compute fitting head losses**
4. **Compute friction factor, *f***
5. **Calculate velocity**
6. **Continue until guessed velocity = calculated velocity.**

Can all be done easily by spreadsheet!