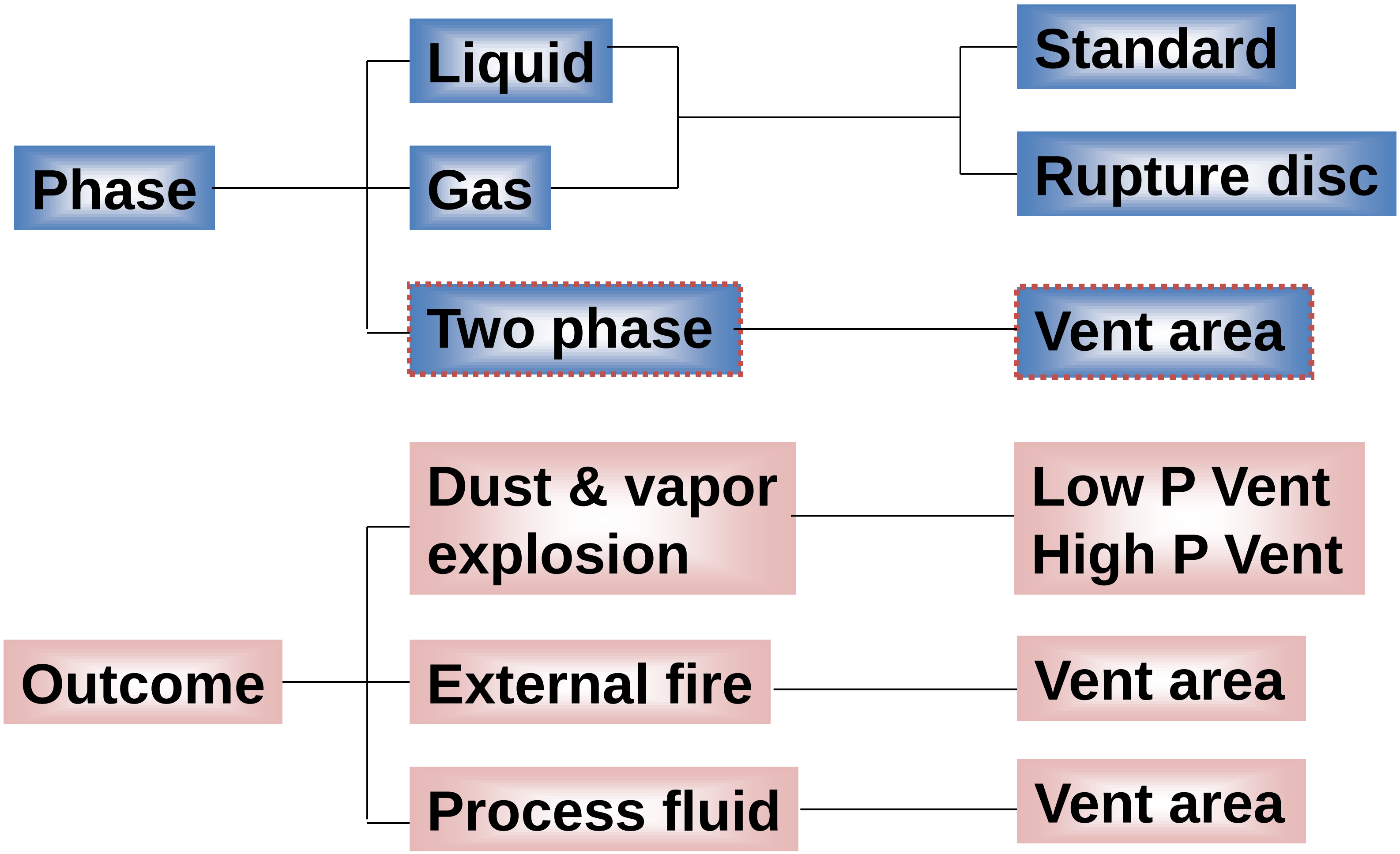
Relief System Sizing

Calculating Relief Size I

- Conventional spring-operated reliefs in liquid or vapor-gas service
- Rupture disc in liquid or vapor-gas service
- Two-phase flow during runaway rxn
- Reliefs for dust and vapor explosion
- Reliefs for external fire
- Reliefs for thermal expansion of process fluid

Calculating Relief Size II



Phase

Liquid

Gas

Two phase

Standard

Rupture disc

Vent area

Outcome

Dust & vapor explosion

External fire

Process fluid

Low P Vent
High P Vent

Vent area

Vent area

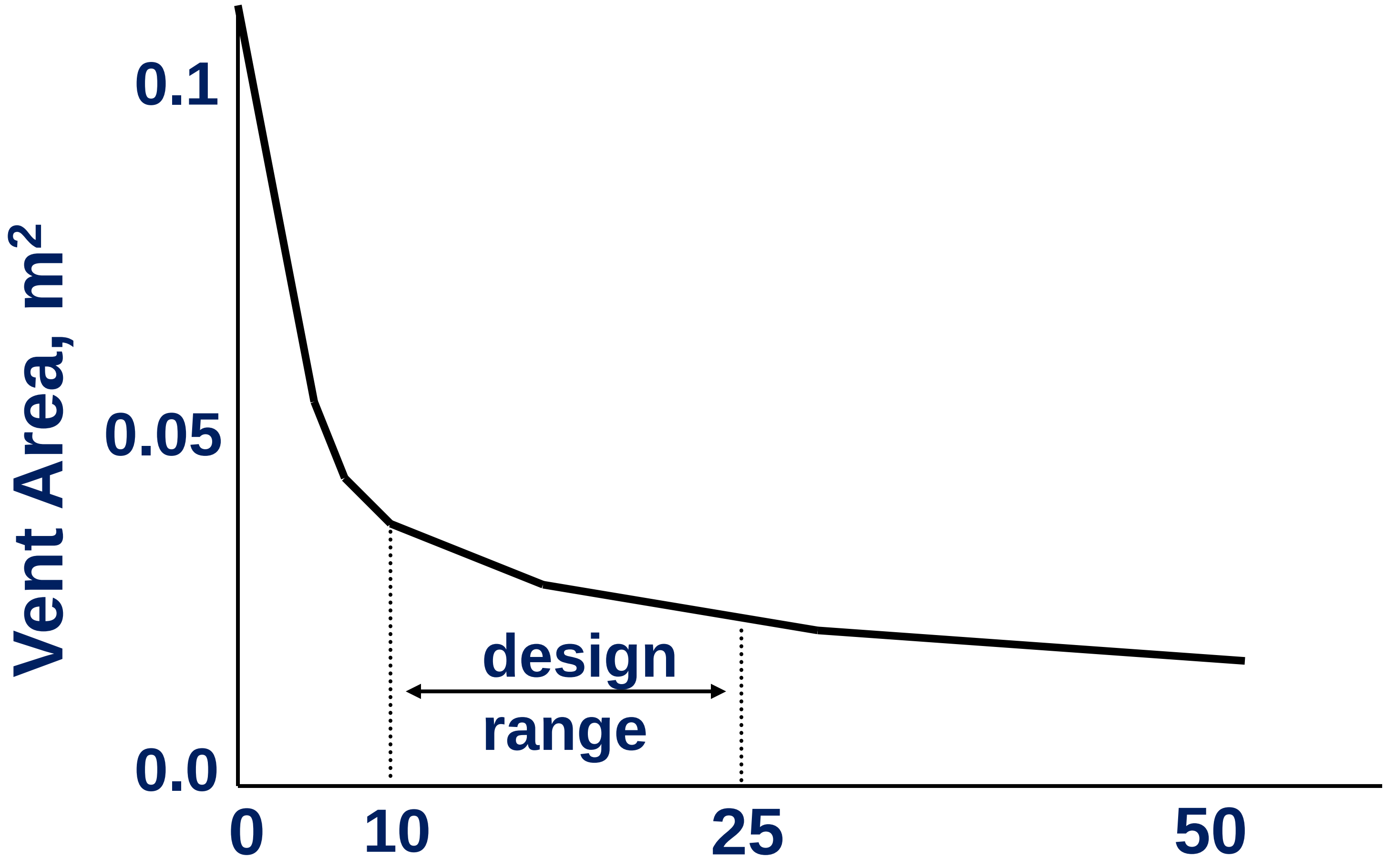
Relief Area Requirements

- **Minimum flow to hold valve seat in open position: 25-30 % of maximum flow**

  - Low flow can lead to rapid opening and closing (*chattering*)

- **Overpressures are designed to be 10 to 25 % above set pressures to prevent excessive vent sizes**
- **To hold pressures near the set pressures would require much larger vent sizes**

Required Vent Area, 2-f Flow



Overpressure, %

Spring Relief Area for Liquids

Assume orifice flow through the valve port:

$$Q_v = \bar{u}\, A = A\, C_o \sqrt{\frac{2 g_c\, \Delta P}{\rho}}$$

Eqn 4-6, p. 114

$$A = \frac{Q_v}{\bar{u}} = \left[\frac{\text{in}^2 (\text{psi})^{1/2}}{38.0\text{gpm}} \right] \frac{Q_v}{C_o} \sqrt{\frac{\rho / \rho_{ref}}{\Delta P}}$$

$\bar{u}$ **is the liquid velocity through the spring relief,**

C_{o} **is the discharge coefficient,**

ΔP **is the pressure drop across the relief, and**

ρ **is the liquid density**

Computed Area for Liquids

- *A* is *computed area* for device sizing as contrasted to *effective valve area* during use
- Max pressure in the API equation is 25 % above the set pressure
- For C_o use the conservative value of 0.61 unless more information is available
- K_v, K_p, K_b are correction factors for use of the API equation with various liquid viscosities, maximum pressures, and backpressure.

Spring Relief Area for Liquids

API correction factors included for wide applications:

$$A = \left[\frac{\mathrm{in}^2\,\mathrm{psi}^{1/2}}{38\,\mathrm{gpm}}\right]\frac{Q_v}{C_o K_v K_p K_b}\sqrt{\frac{\rho/\rho_{ref}}{1.25P_s - P_b}}$$

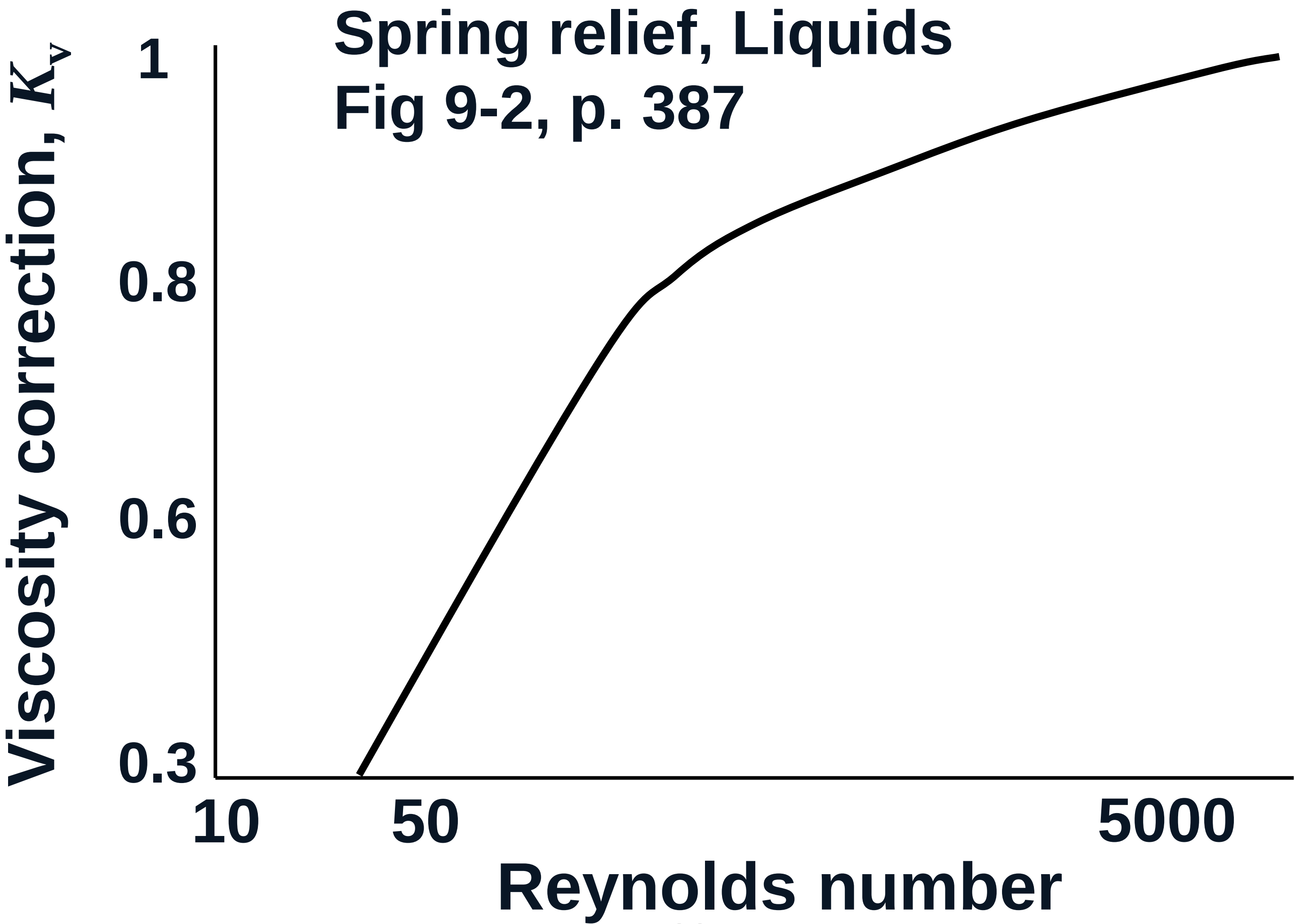
A is the computed relief area (in^2),
Q_v is the volumetric flow through the relief (gpm),
C_o is the discharge coefficient (unitless),
K_v is the viscosity correction (unitless),
K_p is the overpressure correction (unitless),
K_b is the backpressure correction (unitless),
(ρ/ρ_{ref}) is the specific gravity of the liquid (unitless),
P_s is the gauge set pressure ($\mathrm{lb_f/in^2}$)
P_b, is the gauge backpressure ($\mathrm{lb_f/in^2}$)

Correct Area for Viscosity: K_v

- **Higher the viscosity the higher the friction losses through the valve**
- **Higher the viscosity, the smaller the Reynolds number, Re, and smaller the K_v and therefore the larger the required *A***
- ***R_e* usually is > 5,000. Then K_v is ~ 1.**
- **For low Re , K_v *is a* strong function of Re**

$$K_V = \sqrt{\frac{1}{\frac{170}{\mathrm{Re}} + 0.98}}$$

Viscosity Correction Factor: K_v

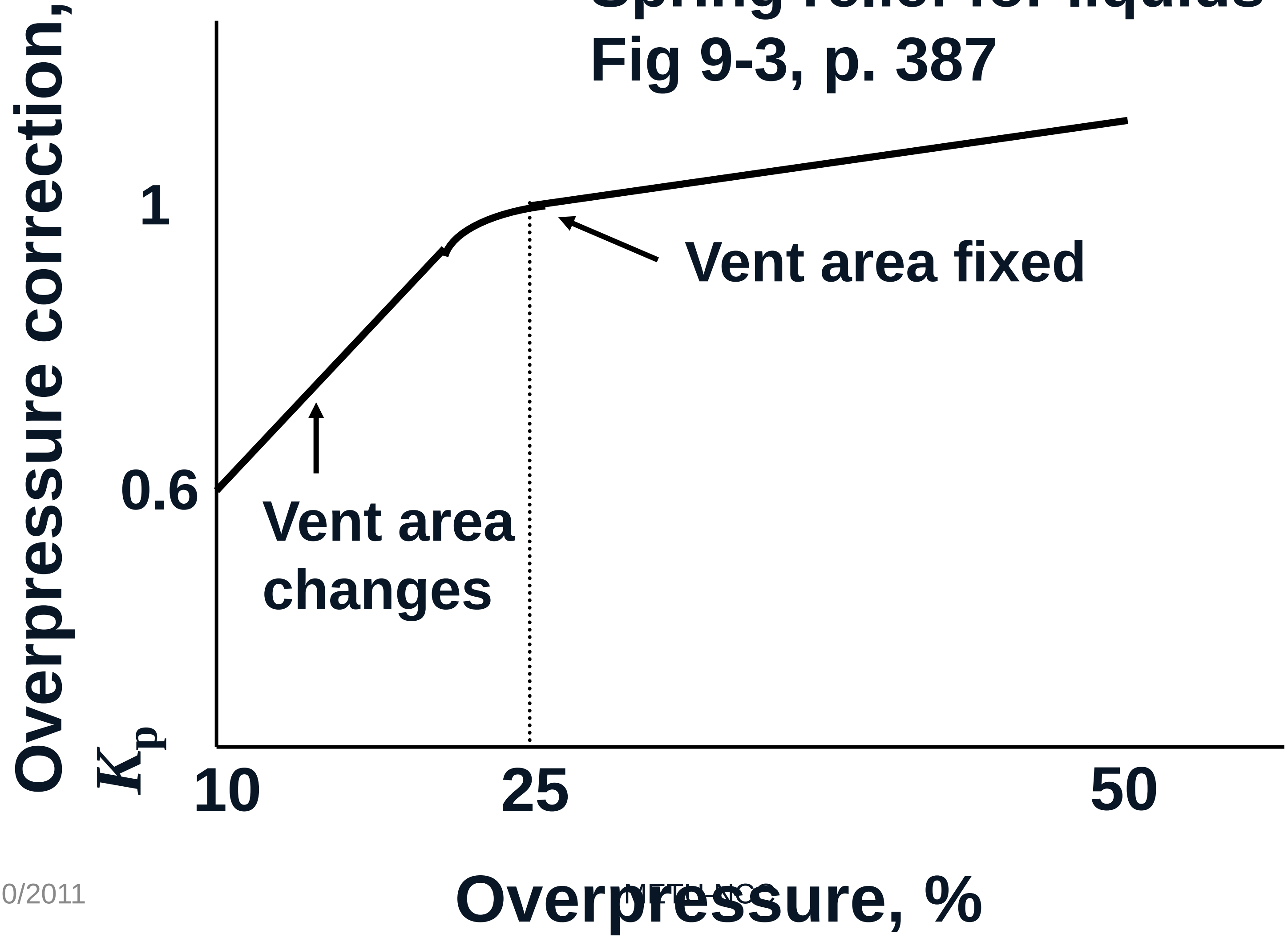


Correct A for Overpressure: K_p

- **1.25 P_s- P_b = ΔP for 25 % overpressure (OP); use a correction factor, K_p , for OP within 10 - 50 %**
- **OP correction factor: K_p = 1 for 25 % OP**
- **Above 25 %, the vent area is fixed, so flow rate change only with pressure drop: K_p is a weak function of pressure in this range**
- **Below 25 %, the vent area changes with pressure, so flow rate changes with pressure drop and with area: K_p is a strong function of pressure in this range.**

Overpressure Correction: K_p

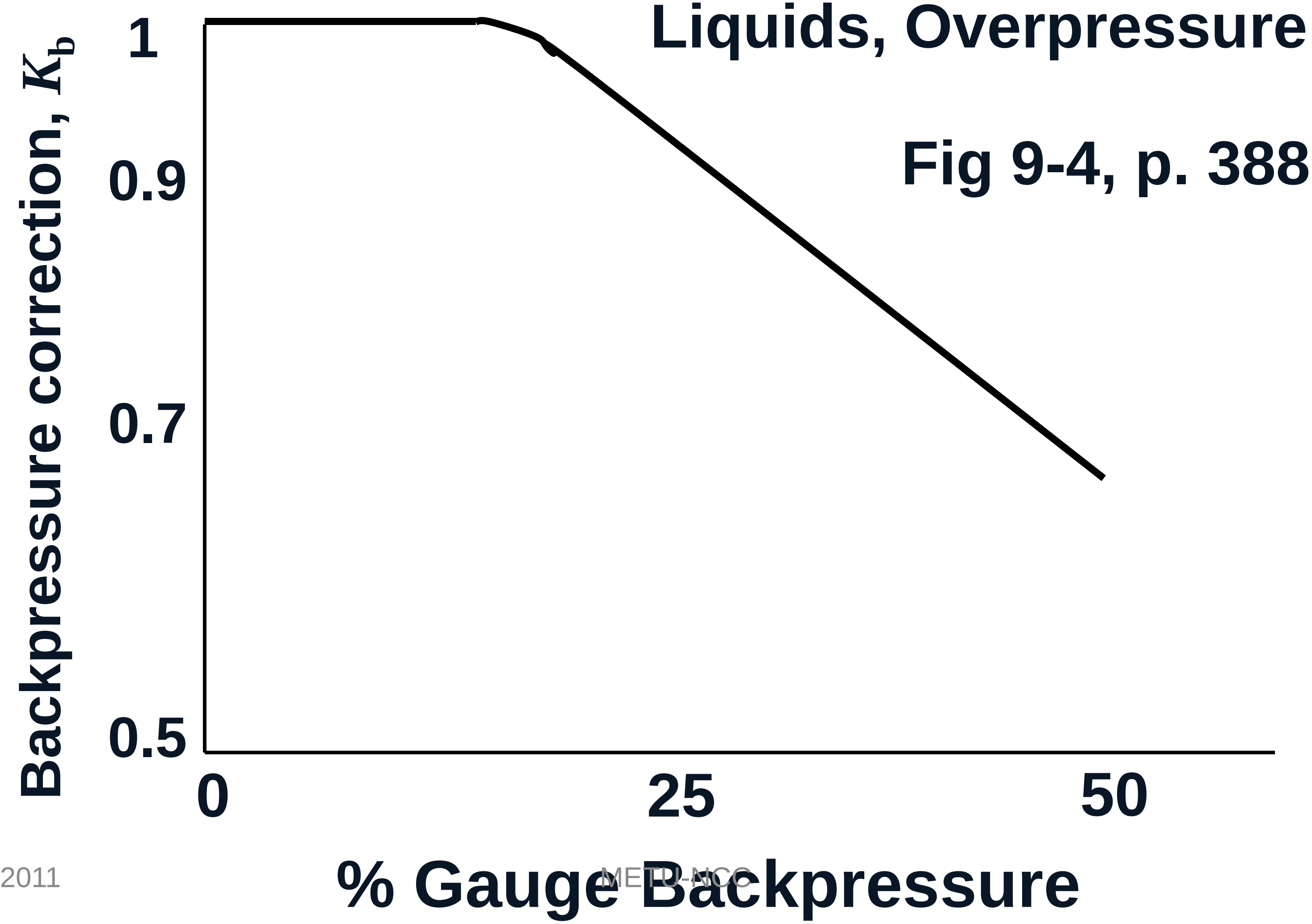
Spring relief for liquids
Fig 9-3, p. 387



Correct Area for Backpressure: K_b

- **P_b in basic API equation corrects for effects of backpressures in conventional valves (set pressure and flow rate**
- **Higher the backpressure, the lower the flow: larger the calculated required area, *A***
- **For balanced bellows valves, a correction factor, K_b, must be included because the set pressure does not increase as backpressure increases**
- **The higher the backpressure, the smaller the K_b and the larger the required *A* for a given Q_v**
- **Ex 9-1, p 388 relief sizing**

K_b for Balanced-Bellows Reliefs



Liquids, Overpressure = 25 %

Fig 9-4, p. 388

Spring Relief Valves for Gases

In general, flow is critical with $P_{\mathrm{ch}} > P_{\mathrm{ext}}$:

$$(Q_m)_{ch} = C_o A P \sqrt{\frac{\gamma g_c M}{R_g T}\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}}$$

Eqn 4-50
p. 133

$$A = \frac{Q_m}{C_o \chi K_b P}\sqrt{\frac{T z}{M}}$$

z, compressibility factor
P, max absolute discharge pressure

$$\chi = \sqrt{\frac{\gamma g_c}{R_g}\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}}$$

Vent Area Equation for Gases

- **Separate K_b correction for each valve type:**
  - **Standard valves, Fig 9-5, balanced bellows, Fig 9-6**
  - **For larger backpressure, K_b smaller and A larger**
- **C_o: if not known use 0.975**
- **M is average molecular weight**
- **P is the maximum absolute relieving pressure:**

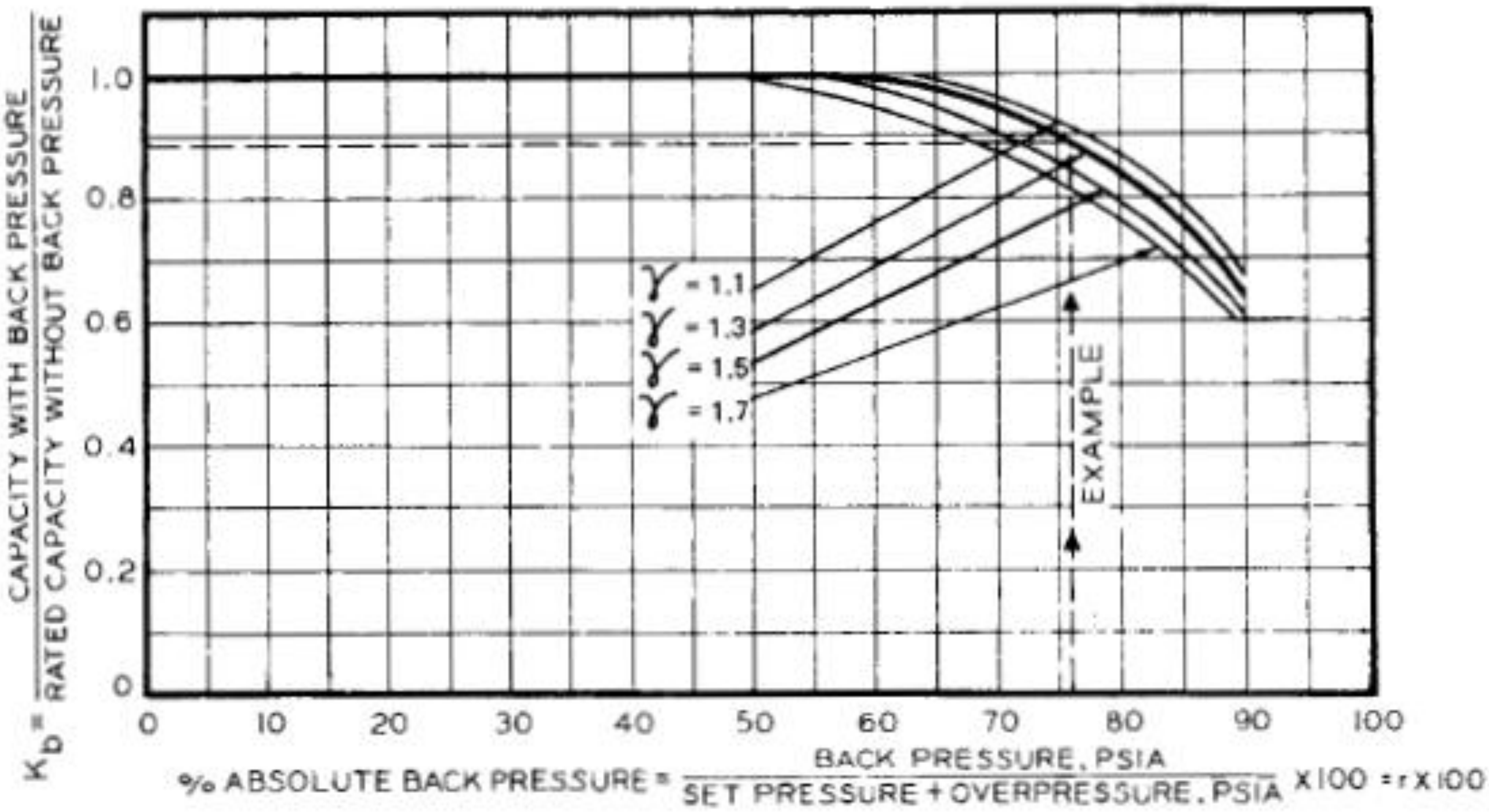
$$P = P_{max} + 14.7$$

- **ASME safety guidelines, P_s = gauge set pressure:**

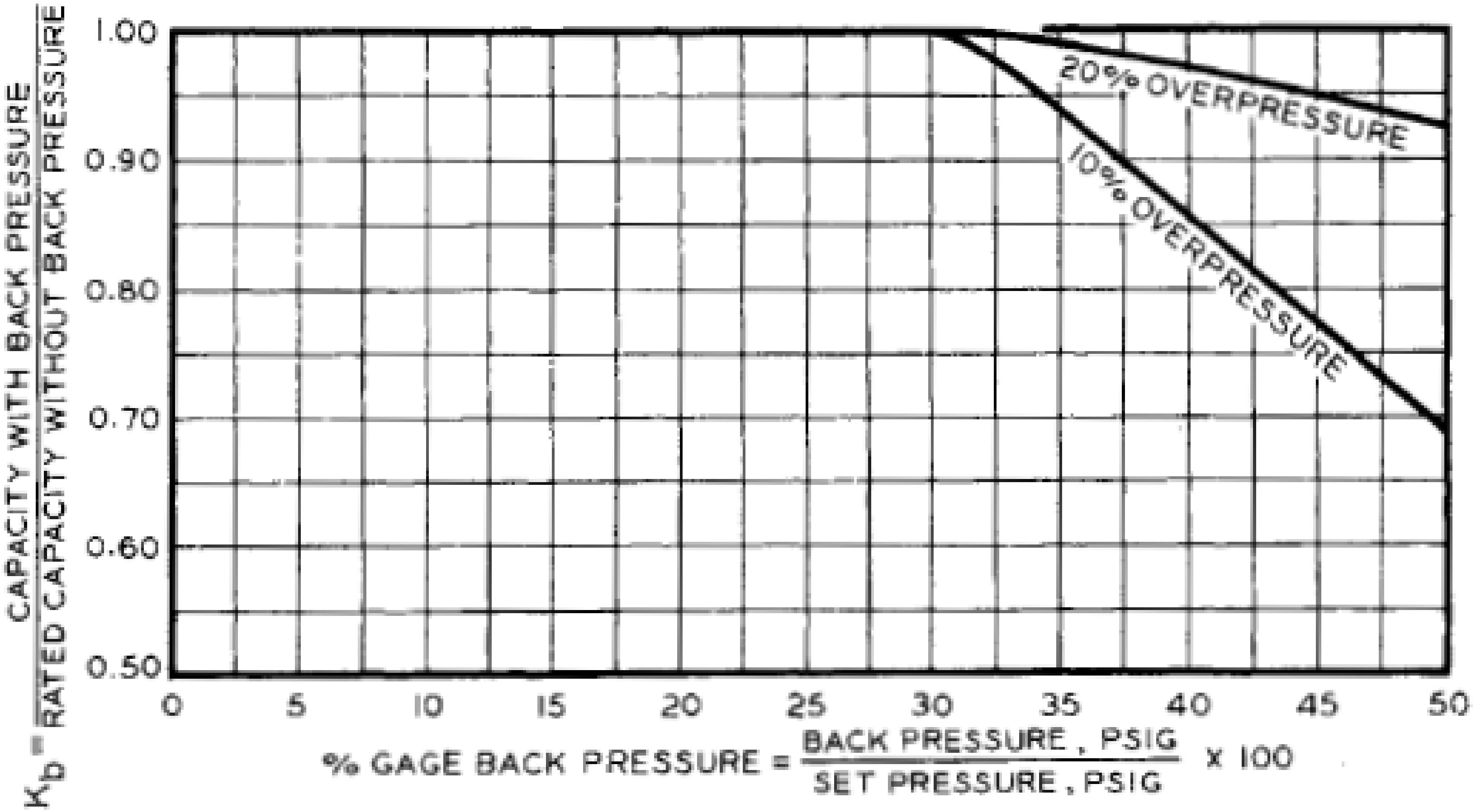
$P_{max} = 1.1P_s$, **unfired vessels**

$P_{max} = 1.2P_s$, **vessels exposed to fire**

$P_{max} = 1.33P_s$, **piping, Ex 9-2, p 392**



Backpressure correction K_b for conventional spring-type reliefs in vapor or gas service. Source: API RP 520



Backpressure correction K_b for balanced-bellows reliefs in vapor or gas service. Source: API RP 520

Rupture Disks for Liquids

- **Use expression for spring relief valves for liquids**

  - Discharge directly to atmosphere or short piping:

$$A = \left[\frac{\mathrm{in}^2(\mathrm{psi})^{1/2}}{38.0\,\mathrm{gpm}}\right]\frac{Q_v}{C_o}\sqrt{\frac{\rho/\rho_{ref}}{\Delta P}}$$

Eqn 9-3, p. 385

- **Discharge to a relief system:**
- **Flow through the system of pipes and other components must be analyzed as considered in study of source terms.**

Rupture Disks for Gases

- **Use expression for spring relief valves for gases**
- **For low backpressure levels with no K_b factor:**

$$A = \frac{Q_m}{C_o \chi P}\sqrt{\frac{T z}{M}}$$

Eqn 9-13, p. 394

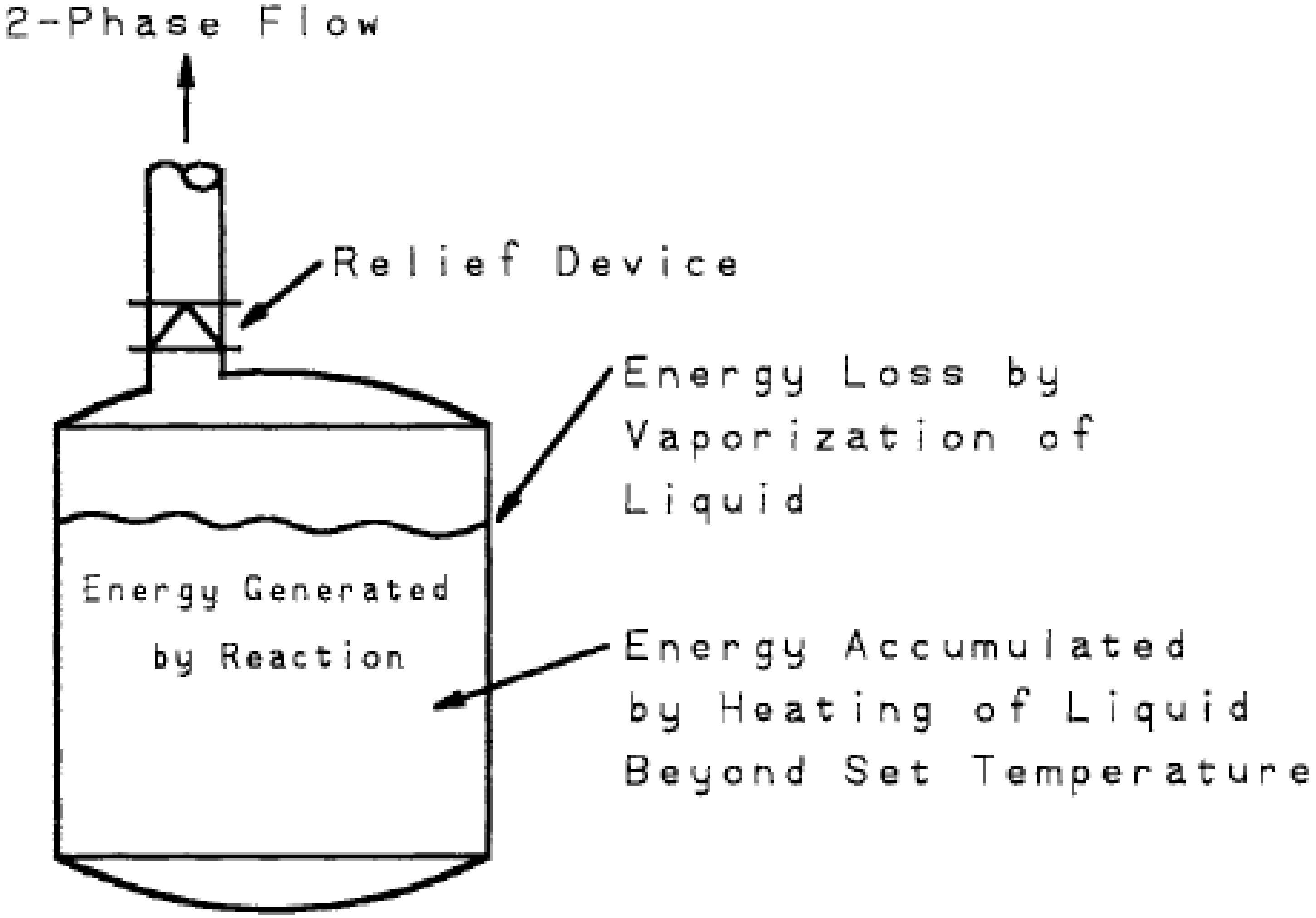
Assumes $C_o = 1$

- **For significant backpressure levels as into a containment system:**

- Analyze discharge and flow through the entire containment system. Ex 9-3,4, p 395

Two-Phase Relief Behavior

- **Choked, two-phase flow through relief orifice**
- **Two-phase flow through containment system**
- **Runaway generally includes flashing during relief; ΔH_v removed (reaction is *tempered*)**
- **Reactor system, large vol/area, ~ *adiabatic***
- **Energy removal only by vaporization and discharge**



A tempered reaction system

Two-Phase Mass Discharge

- **Liquids at their saturation pressure, saturation temperature, T_s, the two-phase mass flow rate:**

Eqn 4-104, p. 156

$$Q_{\mathrm{m}} = \frac{\Delta H_{\mathrm{v}} A}{v_{\mathrm{fg}}} \sqrt{\frac{g_{\mathrm{c}}}{T_{\mathrm{s}} C_{\mathrm{p}}}}$$

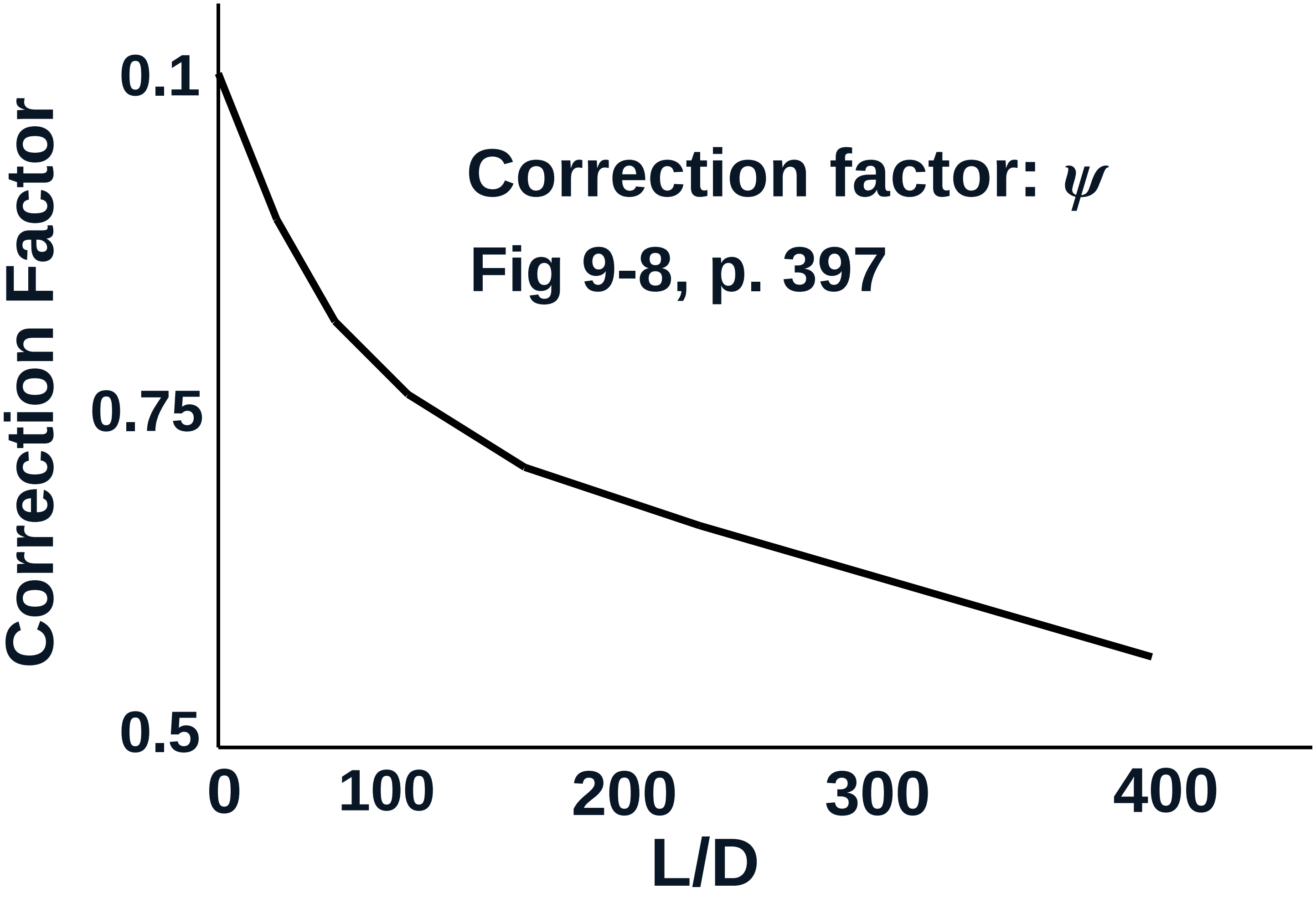
$$v_{\mathrm{fg}} = \Delta \overline{V}^{\,\mathrm{fg}}$$

- **Mass flux with L/D correction factor, ψ, Fig 9-8, p. 397:**

$$G_{\mathrm{T}} = 0.9 \psi \frac{\Delta H_{\mathrm{v}}}{v_{\mathrm{fg}}} \sqrt{\frac{g_{\mathrm{c}}}{C_{\mathrm{p}} T_{\mathrm{s}}}}$$

Empirical 0.9 factor to match data for homogeneous venting

Correction for 2-f Flashing Flow in Pipes



Correction factor: ψ

Fig 9-8, p. 397

Two-Phase Mass Discharge

- **Clausius Clapyron:** $$\frac{dP}{dT} = \frac{\Delta H_{\mathrm{v}}}{T v_{\mathrm{fg}}}$$

$$G_{\mathrm{T}} = 0.9\psi \frac{\Delta P}{\Delta T} \sqrt{\frac{g_{\mathrm{c}} T_{\mathrm{s}}}{C_{\mathrm{p}}}}$$

ψ = 1 for an orifice

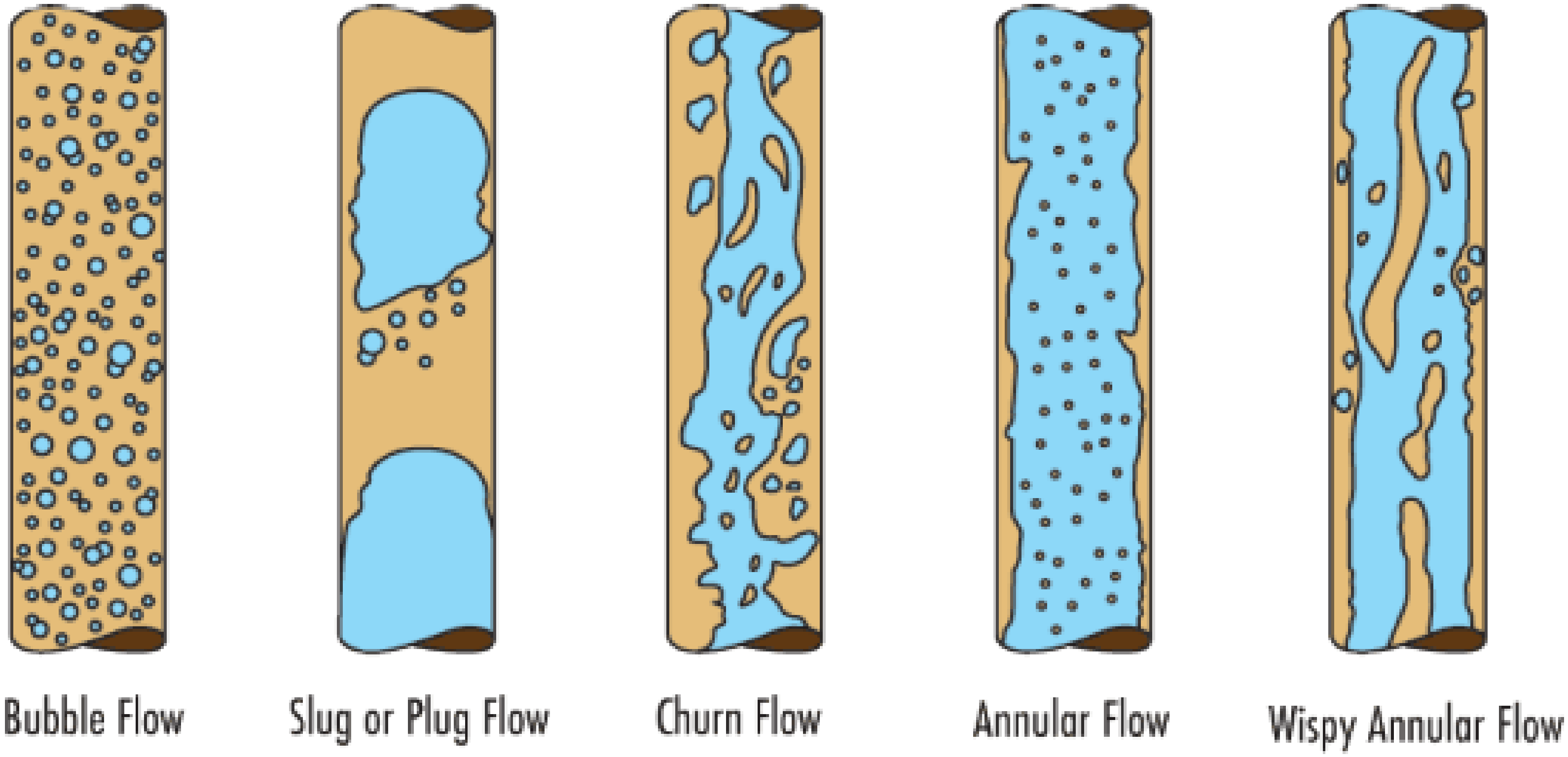
$$A = m_{\mathrm{o}} \dot{q} / G_{\mathrm{T}} \left(\sqrt{\frac{V}{m_{\mathrm{o}}} \frac{\Delta H_{\mathrm{v}}}{v_{\mathrm{fg}}}} + \sqrt{C_{\mathrm{v}} \Delta T} \right)^2$$

m_o = mass before release

With CC equation:

$$A = m_{\mathrm{o}} \dot{q} / G_{\mathrm{T}} \left(\sqrt{\frac{V}{m_{\mathrm{o}}} T_{\mathrm{s}} \frac{dP}{dT}} + \sqrt{C_{\mathrm{v}} \Delta T} \right)^2$$

Heat terms: $\dot{q}$
generated by process,
removed by discharge
adsorbed by evaporate
ΔT due to ΔP (OP)



Patterns of two phase flow

Thermal Reaction Behavior

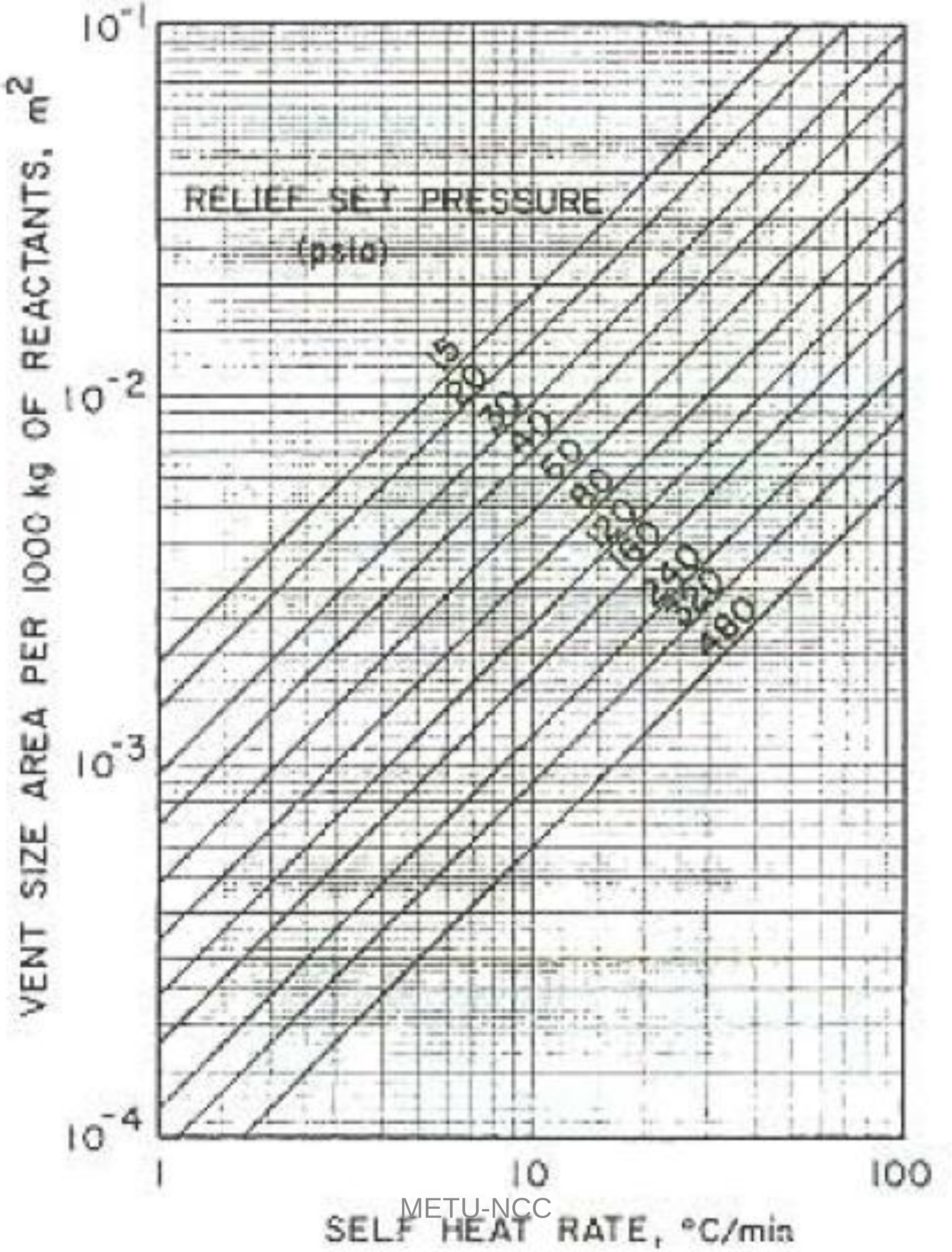
- **Measure heat input rate using a calorimeter, such as VSP, Fig 8-8, p. 366**

$$q = 0.5C_{\mathrm{v}}\left[\left(\frac{dT}{dt}\right)_{\mathrm{s}} + \left(\frac{dT}{dt}\right)_{\mathrm{m}}\right]$$

- **Measure heating rate at the set pressure and the heating rate at the maximum pressure**
- **Understand behavior of two-phase releases**
- **Avoid scenarios that can result in two-phase releases, e.g., overheated polymerization reactor**

Nomograph Sizing Method

- A graphical method by Fauske for quick estimates of two-phase release areas uses only this information:
  - Heating rate at the set temperature, $(dT/dt)_s$
  - Set pressure
  - Mass of reactants
- Obtain a vent size area using Fig 9-9, p. 403
  - Assumes a discharge piping of L/D = 400 (a discharge coefficient = 0.5), and 20 % OP.
- Adjust an area estimate for other L/D ratios and OP values.


VENT SIZE AREA PER 1000 kg OF REACTANTS, m^2
SELF HEAT RATE, °C/min
RELIEF SET PRESSURE
(psia)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
100
15
20
30
40
60
80
120
160
240
320
480

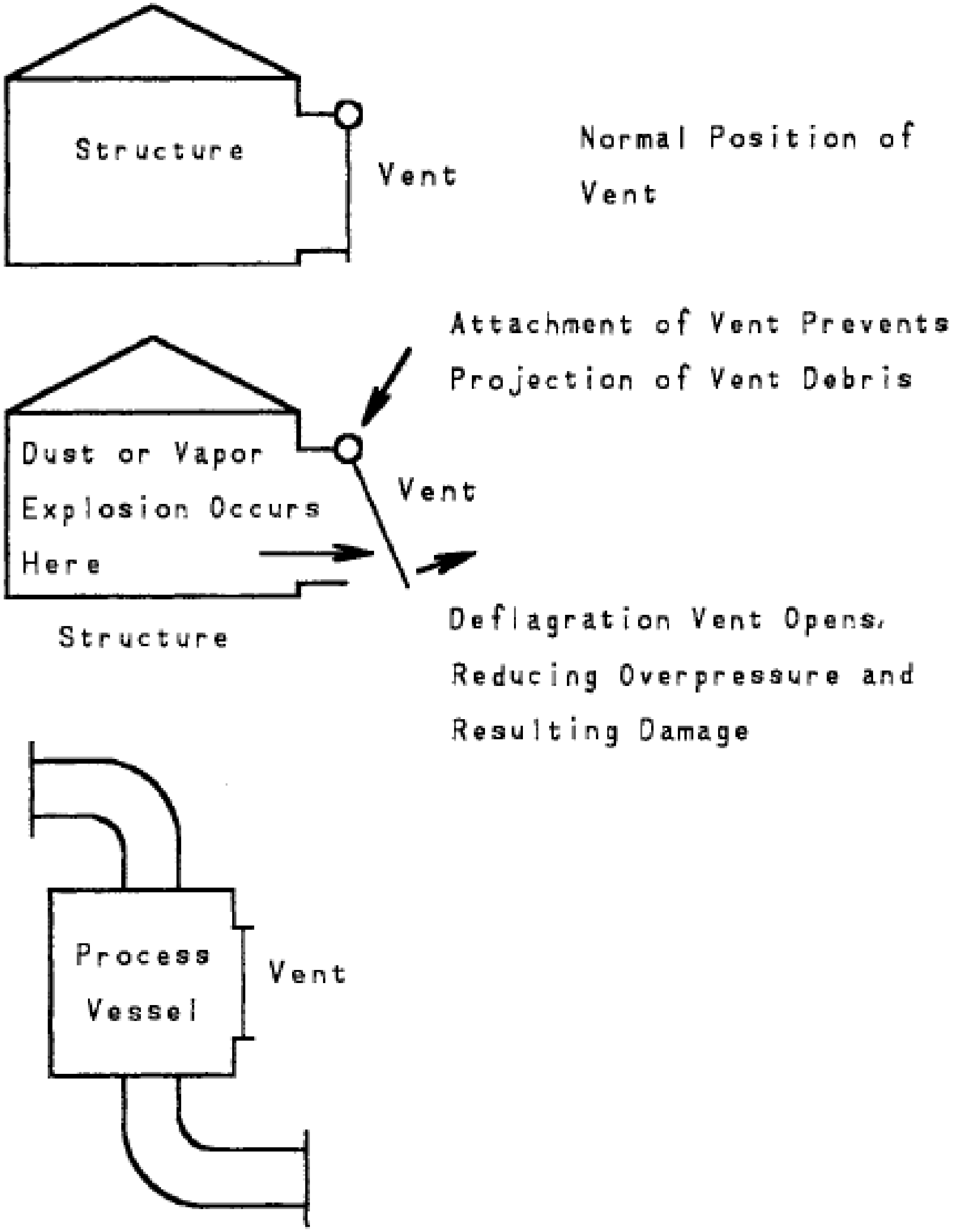


Figure 9-10 Deflagration vents for structures and process vessels.

9-6 Deflagration Venting for Dust and Vapor Explosions

- **Vents for Low-Pressure Structures**

$$A = \frac{C^*_{\text{vent}} L_1 L_2}{\sqrt{P}}$$

by Runes

A **is the required vent area,**

C^*_{vent} **is a constant that depends on the nature of the combustible material,**

L_1 **is the smallest dimension of the rectangular building structure to be vented,**

L_2 **is the second smallest dimension of the enclosure to be vented, and**

P **is the maximum internal pressure that can be withstood by the weakest member of the enclosure.**

- **Vents for High-Pressure Structures**

$$K_{\mathrm{G}} \text{ or } K_{\mathrm{St}} = \left(\frac{dP}{dt}\right)_{\max} V^{1/3}$$

K_G **is the deflagration index for gases and vapors,**

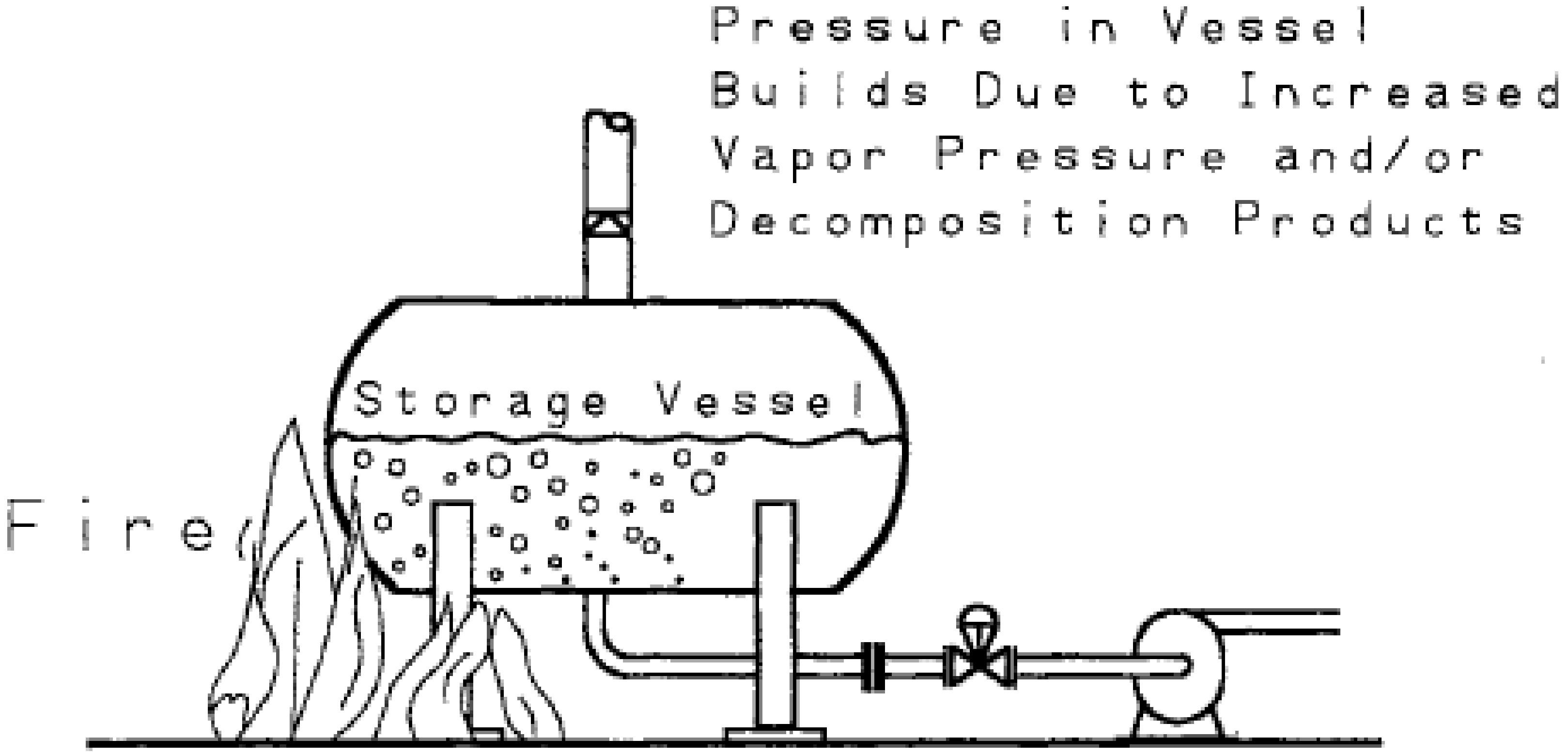
K_{st} **is the deflagration index for dusts,**

$(dP/dt)_{max}$ **is the maximum pressure increase, determined experimentally, and**

V **is the volume of the vessel.**

Reliefs for Fired Reactors

- Reactors exposed to external fires: heating and boiling of process liquids and excessive pressures
- Usually exposure at a small part of reactor surface: two-phase foam is smaller amount than from a runaway reaction
- Help prevent two-phase flow during external fire relief: allow a large vapor space above the liquid
- If reactor not protected, firing can lead to reactor failure and result in a BLEVE (p. 282) and if liquid is flammable, a VCE (p. 281)
- Security results more from inherently safer designs


Pressure in Vessel
Builds Due to Increased
Vapor Pressure and/or
Decomposition Products
Storage Vessel
Fire

$$A = \frac{Q m_o v_{fg}}{G_T V \Delta H_v}$$

Q **is the constant heat input rate,**

G_T **is the mass flux through the relief,**

A **is the area of the relief,**

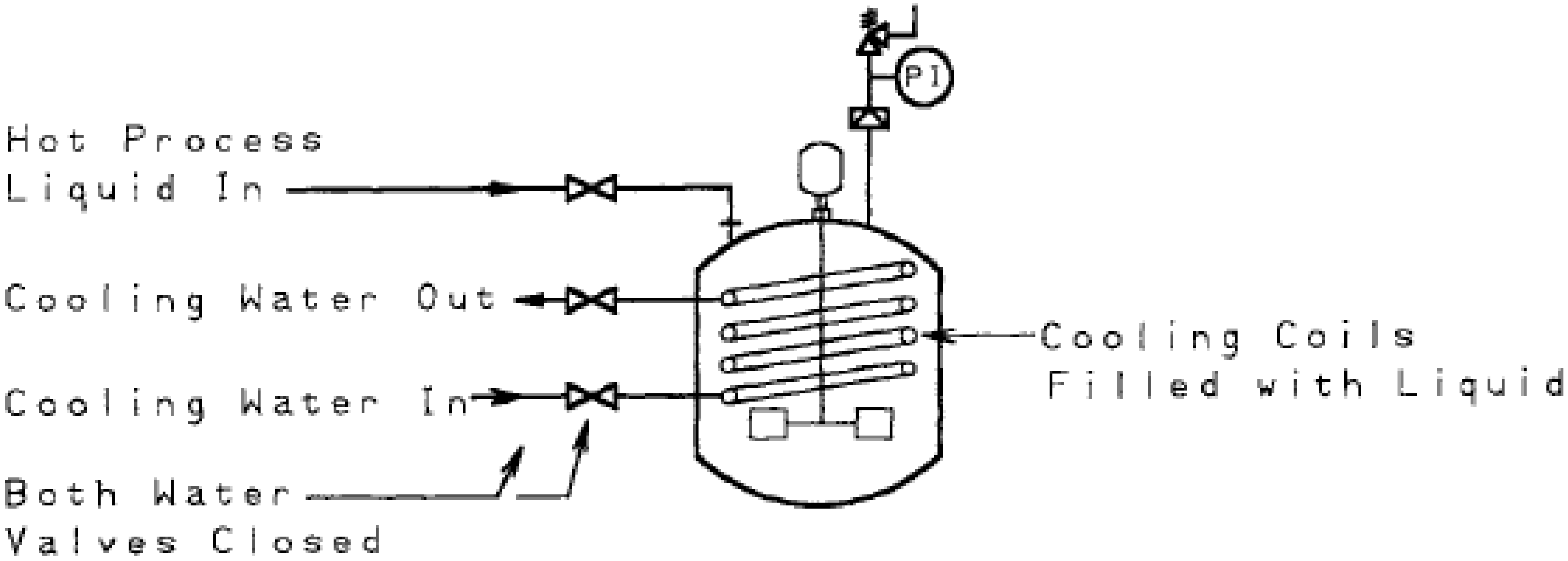
m_o **is the liquid mass in the vessel,**

V **is the volume of the vessel,**

ΔH_v **is the heat of vaporization of the liquid.**

Reliefs for Thermal Expansion of Process Fluids

- Liquids contained process piping expands and damage pipes & vessels
  - Ex; Cooling coil in reactor
  - Contamination of reactor
  - Subsequent corrosion
  - Substantial plant outage
  - Large repair expense



Heat Transfer from Hot Vessel Fluid to Cooling Liquid Increases Cooling Liquid Temperature Leading to Thermal Expansion.

Reliefs for Thermal Expansion of Process Fluids

$$\beta = \frac{1}{V}\left(\frac{dV}{dT}\right)$$

Then, the volumetric expansion rate is expressed

$$Q_v = \frac{dV}{dt} = \frac{dV}{dT}\frac{dT}{dt} = \beta V\left(\frac{dT}{dt}\right)$$

Energy balance with external heating

$$mC_P\frac{dT}{dt} = UA(T - T_a)$$

Reliefs for Thermal Expansion of Process Fluids

Then, the volumetric expansion rate is expressed

$$Q_v = \frac{\beta V}{m C_P} UA(T - T_a) = \frac{\beta}{\rho C_P} UA(T - T_a)$$

Homework due on Jan/6(Thu)
Crowl, Problems 9-1, 2, 5, 19, 28