1 Heat Flux

(Green book pg 44,162; HFPE pg 3-274, Example on 286)

$q_r" = Q_R/(4\pi r^2)$

q_r"≡ Heat flux on target perpendicular to radius from point source

Q_r ≡ Radiative heat release from fire (20 to 30% of Q_c)

r ≡ R ≡ Distance from plume center at h/2 to target

NEED TO LOOK AT HPFE 1-4 FOR CONFIGURATION (SHAPE) FACTORS Table 1-4.1 pg 1-77 & Appendix pg A-43

2 Emissivity

(HFPE 3-277-278)

q = esT^4

q = flame emissive power kW/m^2

e = 1.0 for a blackbody

s = 5.67 x 10^{-12} (kW/m^{2}K^4 - Stefan-Boltzman Constant)

T is in Kelvin

3 Blast Wave Energy

(Green book pg 46)

$E = \alpha \Delta H_C m_F$

E ≡ Blast wave energy (kJ)

α ≡ A ≡ Yield (Fraction of available combustion energy participating in blast wave generation. Conservative value is 0.5)

ΔHc ≡ C ≡ Theoretical net heat of combustion (kJ/kg)

m_F ≡ M ≡ Mass of flammable vapor released (kg)

4 TNT Mass Equivalent

(Green book pg 46)

$W\_TNT = E / 4500$

W_{TNT} ≡ Equivalent weight of TNT in kg

E ≡ Blast wave energy in kJ

5 BLEVE

(Green book pg 49)

$E = m(u_r - u_a)$

E ≡ Blast wave energy

m ≡ Mass of liquid in vessel

U_r ≡ Internal energy (per unit mass) of liquid at rupture

U_a ≡ Internal energy (per unit mass) of vapor after expansion

6 Fireball

(Green book pg 49 and 50; HFPE pg 3-306)

$D_{max} = 5.25m^{0.314}$

$Z_p = 12.73\ V_{va}^{1/3}$

$q_{max} = 828m^{0.771}/R^2$

D_{max} ≡ Maximum diameter of fireball (m)

m ≡ Mass of fluid (kg)

Z_p ≡ Rise of **center** of fireball above tank (m)

V_{va} ≡ Fuel vapor volume (m^3)

q_{max} ≡ Peak thermal radiation from fireball (kW/m^2)

m ≡ mass of fuel (kg)

R ≡ Distance of center of fireball to target (m)

7 Pool Fires Mass Loss Rate

(Green book pg 103,163; NFPA 92B Annex B)

$m" = m_\infty^"(1 - e^{-k\beta D})$

m" ≡ large pool burning rate

$m^"_\infty$ ≡ Mass loss rate for an infinite pool diameter

kβ ≡ Extinction absorption coefficient (SPFE pg 3-26 or NFPA 92B Table B.5.1)

8 Total Heat Generated

(Green book Answer Manual pg 8)

$Q = \eta * m' * \Delta H_C$

Q ≡ Total Heat Generated

η ≡ Radiative fraction of combustion energy (calculated from HFPE pg 3-111 $\eta = {}^{H_R}/_{H_T}$)

m' ≡ Mass burning rate of fuel

ΔH_c ≡ Heat of combustion

q" = Q/4πr^2

q" ≡ heat flux, r meters from point source

9 Energy Absorbed

(Green book Answer Manual pg 9)

$E = \varepsilon * q" * A * t$

E ≡ Energy absorbed

ε ≡ Emissivity

q" ≡ Heat flux

A ≡ Exposed area

t ≡ time

10 Heat Release Time growth

(Green book pg 139 & HFPE pgs 4-10 to 4-17)

$Q(t) = \left(\frac{1055}{t_g^2}\right) * t^2$

Q(t) ≡ Total heat release rate at time t (kW)

t ≡ Time in seconds

t_g ≡ Time for a fire to grow from first appearance of flame to 1,055 kW (1,000 Btu/s)

Common t_g = 75 for ultrafast fires, 150 for fast fires, 300 for medium fires, and 600 for slow fires

11 Lower Flammable Limit

(Green book pg 147)

$LFL = V_{LFL}/0.147$

LFL ≡ lower flammable limit

V_{LFL} ≡ Vapor pressure of liquid @ its LFL, psia

$LFL = V_{LFL}/1.01$

LFL ≡ lower flammable limit

V_{LFL} ≡ Vapor pressure of liquid @ its LFL, kPa

$LFL = 100V/P$

LFL ≡ lower flammable limit

V ≡ Vapor pressure of liquid @ its LFL @ ambient pressure

P ≡ Ambient pressure

12 Exit sign visibility

(Green book pg 152; HFPE pg 2-263-265)

$KS = 8\ for\ light\ emitting\ exit\ sign$

$KS = 3\ for\ light\ reflecting\ exit\ sign$

K ≡ extinction coefficient (m^{-1})

S ≡ visibility (m)

$\frac{I}{I_0} = e^{-KL}$ Bouguer's Law

$\frac{I}{I_0} = 10^{-DL}$

D = K/2.303

$D_s = DV_c/A$

$D_m = DV_c/DM$

$K = K_m m$

I ≡ Intensity of Light through Pathlength (L) of Smoke

I_0 ≡ Intensity of Incident Monochromatic Light

D ≡ Optical Density per Meter

D_s ≡ Specific Optical Density (dimensionless)

D_m ≡ Mass Optical Density (m^2/g) HFPE 2-264 Table 2-13.5

V_c ≡ Volume of space being filled with smoke (m^3)

A ≡ Area of Sample being burned (m^2)

K ≡ extinction coefficient (m^{-1})

K_m ≡ extinction coefficient per unit mass ~ 7.6 m^2/g (flaming fire of wood and plastics – use unless other info given) OR ~ 4.4 m^2/g (pyrolysis fire)

DM ≡ amount of material that burns (**grams**)

m ≡ mass concentration of smoke aerosol

13 Compartment Fires

(Green book pg 154; HFPE pg 3-176; FPH pg 3-150 thru 152)

Use Law's formula to calculate post-flashover compartment fire temperatures (HFPE pg 3-183; FPH pg 3-127)

14 McCaffrey Flashover Heat Release Equations

(Green book pg 164; HFPE pg 3-184-186)

$$Q_{fl} = 610(h_k A_T A_O \sqrt{H_O})^{1/2}$$

Q_{fl} ≡ Heat Release rate required for flashover (kW)

h_k ≡ Effective heat transfer coefficient ((kW/m)/K)

A_T ≡ Total area of compartment surfaces (m^2)

A_O ≡ Area of opening (m^2)

H_O ≡ Height of opening (m)

$h_k = \frac{k}{\delta}$ where time of exposure (t) > thermal penetration time (t_p)

$h_k = (k\rho c/t)^{½}$ where $t <= t_p$

k ≡ Thermal conductivity of wall material HFPE A-28-33

δ ≡ Thickness

$t_p = (\rho c/k)(d/2)^2$

ρ ≡ density of compartment surface (kg/m^3)

c ≡ specific heat of compartment surface material (kJ/m-K)

k ≡ thermal conductivity of compartmt surface (kW/ m-K)

d ≡ thickness of compartment surface (m)

14A Pre-Flashover Compartment Temps – Natural Ventilation

(HFPE pg 3-175-177; FPH 3-151)

$$\Delta T_g = 480\left(\frac{Q}{\sqrt{g}(c_p\rho_\infty T_\infty A_O)\sqrt{H_O}}\right)^{\frac{2}{3}}\left(\frac{h_k A_T}{\sqrt{g}(c_p\rho_\infty A_O)\sqrt{H_O}}\right)^{-\frac{1}{3}}$$

$DT_g = T_g - T_\infty$

DT_g ≡ Upper gas temperature rise above ambient (Kelvin)

T_g ≡ Upper gas temperature (Kelvin)

T_∞ ≡ Ambient gas temperature (Kelvin)

Q ≡ **Total** Heat Release Rate (kW)

h_k ≡ Effective heat transfer coefficient (**thermal inertia**)

$h_k = (k c\rho/t)^{½}$ (Note: c,ρ may not be same↓) (kW/m*Kelvin)

A_T ≡ Total area of compartment enclosing surfaces (m^2)

A_O ≡ Area of opening (m^2)

H_O ≡ Height of opening (m)

g = 9.8 m/s^2

c_p = 1.05kJ/kg*K (specific heat)

ρ_∞ = 1.2 kg/m^3 (density)

T_∞ = 295 K (Kelvin)

14B Pre-Flashover Compartment Temps – Natural Ventilation @ STP

(HFPE pg 3-175-177; FPH 3-151)

$$\Delta T_g = 6.85\left(\frac{Q^2}{h_k A_T A_O \sqrt{H_O}}\right)^{1/3}$$

$DT_g = T_g - T_\infty$

DT_g ≡ Upper gas temperature rise above ambient (Kelvin)

T_g ≡ Upper gas temperature (Kelvin)

T_∞ ≡ Ambient gas temperature (Kelvin)

Q ≡ **Total** Heat Release Rate (kW)

h_k ≡ Effective heat transfer coefficient ((kW/m)/Kelvin)

A_T ≡ Total area of compartment enclosing surfaces (m^2)

A_O ≡ Area of opening (m^2)

H_O ≡ Height of opening (m)

14C Pre-Flashover Compartment Temps – Forced Ventilation

(HFPE pg 3-177-178; FPH 3-151)

$$\frac{\Delta T_g}{T_\infty} = 0.63\left(\frac{Q}{m_g T_\infty c_p}\right)^{0.72}\left(\frac{h_k A_T}{m_g c_p}\right)$$

$DT_g = T_g - T_\infty$

DT_g ≡ Upper gas temperature rise above ambient (Kelvin)

T_g ≡ Upper gas temperature (Kelvin)

T_∞ ≡ Ambient gas temperature (Kelvin)

Q ≡ **Total** Heat Release Rate (kW)

h_k ≡ Effective heat transfer coefficient ((kW/m)/Kelvin)

A_T ≡ Total area of compartment enclosing surfaces (m^2)

c_p ≡ specific heat of gas (kJ/kg-K)

m_g ≡ compartment mass ventilation rate (kg/s)

m_g is (m^3/s)(1.18 kg/m^3) {5000 cfm ~ 2.4 m^3/s}

14D Flashover Reference

(Review Slides)

When flashover occurs, $T_g \sim 600^oC$ and $q_r \sim 20kW/m^2$

15 Virtual Origin of Pool Fire

(Green book pg 144; HFPE pg 2-9; FPH pg 3-155)

$$z_o = -1.02D + 0.083Q^{2/5}$$

Z_0 ≡ Virtual Origin

D ≡ Effective diameter (m)

Q ≡ **Total** heat release rate (kW)

15A Virtual Origin of Other Fire Types

(Green book pg 144; HFPE pg 2-9; FPH pg 3-155)

$$z_o = L - 0.175Q^{2/5}$$

z_0 ≡ Virtual Origin

L ≡ Flame Height (m)

Q ≡ **Total** heat release rate (kW)

16 Peak Heat Release Rate

(Green book pg 163; NFPA 92B Annex B)

$$\dot{Q} = m^{"}A * \Delta H_C$$

Q ≡ Peak Heat Release Rate (kW)

$m^{"}$ ≡ mass loss rate per unit area of fuel from equation 8 (kg/s)

A ≡ Area (m^2)

ΔH_C ≡ Heat of Combustion (kJ/kg)

17 Pipe Schedule Correction Factor

(Green book pg 242; NFPA 13 22.4.3.1.1)

$$Correction\ factor = \left(\frac{d_{actual}}{d_{sched\ 40}}\right)^{4.87}$$

d_{actual} ≡ Pipe diameter for schedule pipe being used (in)

d_{actual} ≡ Pipe diameter for schedule 40 pipe (in)

18 Hydrant Flow Test

(Green book 258, Green book Answer Manual pg 11; NFPA 24 C.4.10.1.2)

$$Q_2 = Q_1 \frac{(S-R_2)^{0.54}}{(S-R_1)^{0.54}}$$

$$Q = G * ((S-P)^{0.54})/((S-R)^{0.54})$$

Q ≡ G ≡ Flow (gpm)

S ≡ Static pressure (psi)

R ≡ P ≡ Residual pressure (psi)

(FPH pgs 15-40 through 15-45)

$$Q = 29.84cd^2\sqrt{pitot}$$

c ≡ constant based upon hydrant outlet (.9, .8, .7)

d ≡ diameter of opening (inches)

pitot ≡ velocity pressure of water exiting hydrant (psi)

19 Sprinkler System K-Factor to balance pressures

(Green book pg 195; NFPA 13-22.4.2.4.3;)

$$K_{total} = \frac{Q_{total}}{\sqrt{p_{required}}}$$

$K_{total} = K_{branch1} + K_{branch2} + ... + K_{branchn}$

K_{total} ≡ Sprinkler System K-factor

Q_{total} ≡ Total System Flow (gpm)

$P_{required}$ ≡ Required System Pressure (psi) (**NOT** additive – use highest pressure of any single branch line)

20 Sprinkler Head flow using Sprinkler K-Factor

(Green book pg 195; FPH pg 15-48; FPH pg 16-25)

$$Q = k * \sqrt{p}$$

$k = 29.84cd^2$

d ≡ diameter of opening (inches)

c ≡ coefficient of friction (0.75 for sprinkler heads)

Q ≡ System Flow (gpm)

P ≡ System Pressure (psi)

21 Sprinkler Flow Normal Pressure

(Green book pg 195; NFPA 13-22.4.2.3)

$$P_n = P_t - P_v$$

P_n ≡ Normal pressure

P_t ≡ Total pressure

P_v ≡ Velocity pressure

22 Sprinkler Flow Velocity Pressure

(Green book pg 196; NFPA 13-22.4.2.2)

$$P_v = {0.001123Q^2}/{d^4}$$

P_v ≡ Velocity pressure (psi)

Q ≡ Flow prior to orifice (gpm)

d ≡ Pipe inside diameter prior to orifice (inches)

Find d using HFPE pg A-47

23 Conservation Equation/Bernoulli Equation

(Green bk 235; FPH pg 13-29; 15-39; HFPE pg 4-47)

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 + H_A - H_L - H_E = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

Total Energy 1st loc. + & - = Total Energy 2nd loc.

$$p_T = p + \frac{\rho V^2}{2} + \rho g Z$$

p_T ≡ Total pressure (psi)

p ≡ Normal pressure (psi)

ρ ≡ Fluid density in mass per unit volume

V ≡ Fluid velocity (ft/s)

g ≡ Gravitational constant

Z ≡ Vertical distance from an arbitrary elevation

H ≡ Pluses & Minuses due to pumps, elevation changes, flowing heads, etc.

24 Darcy-Weisbach Equation (foam concentrate, antifreeze >40 gal, & water mist)

(Green book 236; FPH 15-52; HFPE 4-37)

$$h = \left(\frac{f}{D}\right)\left(\frac{v^2}{2g}\right) = \left(\frac{f}{D}\right)\left(\frac{1}{2g}\right)\left(\frac{16}{\pi^2}\right)\left(\frac{Q^2}{D^4}\right)$$

$$h_L = \frac{fLv^2}{2Dg}$$

h ≡ Friction loss over a unit length of pipe

h_L ≡ Friction loss over a entire length of pipe

L ≡ Length of pipe

f ≡ Friction factor

D ≡ Pipe diameter

v ≡ Fluid velocity

g ≡ Gravitational constant

Q ≡ Flow rate

$$h = \frac{0.0135flQ^2}{D^5}$$

f ≡ comes from Moody Diagram = 64/Re

Need to know pipe roughness, ε, from HFPE pgs 4-51 - 53

Reynolds Number, $Re = \frac{vD}{V}$

V ≡ Kinematic viscosity

25 Piping Loops

(Green book 244)

$$A = \sum_{i=1}^{x}\left[\frac{L_i}{c_i^{1.85}d_i^{4.87}}\right] \textit{ for Leg 1 of the loop}$$

$$B = \sum_{j=1}^{y}\left[\frac{L_j}{c_j^{1.85}d_j^{4.87}}\right] \textit{ for Leg 2 of the loop}$$

$$Q_1 = Q_3\left[\frac{B^{0.54}}{(A^{0.54}+B^{0.54})}\right]$$

$$Q_2 = Q_3 - Q_1$$

L ≡ Length of pipe (ft)

d ≡ Pipe diameter (in)

c ≡ Pipe C-factor

Q ≡ Pipe flow (gpm)

Equivalent Pipe:

Series: $FLC_e = FLC_1 + FLC_2 + FLC_3 + ...$

Parallel: $(1/FLC_e)^{0.54} = (1/FLC_1)^{0.54} + (1/FLC_2)^{0.54} + (1/FLC_3)^{0.54} + ...$

$FLC_e = 4.52L_e/(C_e^{1.85}D_e^{4.87})$

L_e ≡ Equivalent Length of pipe (ft)

D_e ≡ Equivalent Pipe diameter (in)

C_e ≡ Equivalent Pipe C-factor

FLC_e ≡ Equivalent Pipe flow (gpm)

26 Pump Caviation

(Green book 245; FPH pg 13-25)

Cavitation occurs when normal water pressure in pipe drops below water vapor pressure

27 Water Hammer

(Green book 246; FPH pgs 15-59 & 60; HFPE pgs 4-67 thru 67)

28 Pump Affinity Laws

(Green book pg 211; FPH pg 15-91)

Law 1 – Constant Speed

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}, \frac{H_1}{H_2} = \frac{N_1^2}{N_2^2}, \frac{bhp_1}{bhp_2} = \frac{N_1^3}{N_2^3}$$

Law 2 – Constant Diameter

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2}, \frac{H_1}{H_2} = \frac{D_1^2}{D_2^2}, \frac{bhp_1}{bhp_2} = \frac{D_1^3}{D_2^3}$$

Q ≡ Capacity (gpm)

N ≡ Specific speed number

H ≡ Head (ft)

bhp ≡ Brake horsepower

D ≡ Impeller diameter

29 Fire Pump Total Head

(Green book pg 210; FPH pg 15-89)

$$H = h_d + h_{Vd} - h_s - h_{Vs}$$

H ≡ Total head (ft)

h_d ≡ Discharge head (ft)

h_{Vd} ≡ Discharge velocity head (ft)

$$h_{Vd} = \frac{V_d^2}{2g}$$

h_s ≡ Total suction head (ft)

$$h_{Vs} = \frac{V_s^2}{2g}$$

V ≡ Velocity (ft/sec) discharge or suction velocity

g ≡ Acceleration due to gravity (32.2 ft/s^2 or 9.81 m/s^2)

30 Pump Brake Horsepower

(Green book pg 212; FPH pg 15-97-98)

$$bhp = \frac{QP}{1710E}$$

bhp ≡ Brake Horsepower

hp ≡ Hydraulic Horsepower = QP/1710

Q ≡ Flow (gpm)

P ≡ Total pressure (psi) = (Total head)(0.433)

E ≡ Pump efficiency (decimal); Usually 60 to 75% (typically assume 65% @ 160% capacity) Remember, typical psi is 65% @ 150% capacity or 55% @ 160% capacity.

Deratings for Altitude and Temperature:

Altitude: 3% for every 1000 ft. above 300 ft.

Temperature: 1% for every 10^{o}F above 77^{o}F

$bhp_{before\ derating} = bhp_{after\ derating}/(1-(A+T))$

Max Pump Churn = 1.4(rated psi) + city psi if using booster

Max Flow = 1.5(rated gpm) @ 0.65 (rated psi)

$bhp_{max\ flow}$ = (max flow)[(0.65)(rated psi)]/1710E

See FPH for SI units.

31 Velocity Head

(Green book 235; FPH pg 15-38)

$h_V = Q^2/891d^4$

h_v ≡ Velocity head (psi)

Q ≡ Flow rate (gpm)

d ≡ Pipe inside diameter (in)

31A Net Positive Suction Head (NPSH_)

$NPSHA = P_{atm} + P_{Static} - f - P_{vapor}$

NPSH ≡ Net Positive Suction Head (psi)

P_{atm} ≡ Atmospheric Pressure (14.7 psia)

P_{static} ≡ pressure tank pressure - height*0.433 (psi)

f ≡ friction loss in line (psi)

P_{vapor} ≡ Vapor Pressure (psig) adjust for Temp and Altitude

31B Diesel Fuel Tank Capacity

(NFPA 20, Chapter 11)

1 gallon/bhp + 5% for expansion + 5% for sump, so effectively, 1.1 gallons/bhp

32 Fire Pump Controller Operation

(Green book pg 224; NFPA 20 A.14.2.7(4))

Jockey pump stop = Fire pump churn + minimum static suction

Jockey pump start ≤ Jockey pump stop – 10 psi

Fire pump #1 start = Jockey pump start – 5 psi

Fire pump #2 start = Fire pump #1 start – 10 psi

Fire pump stop = Fire pump + minimum static suction

33 Sprinkler Flow Pressure Loss Hazen-Williams

(Green book pg 196; NFPA 13-22.4.2.1.2; FPH 15-53)

$p = 4.52Q^{1.85}/(C^{1.85}d^{4.87})$

p ≡ Pressure lost per foot of pipe in psi

Q ≡ Flow rate (gpm)

C ≡ Hazen Williams coefficient

d ≡ Internal pipe diameter (inches)

Find C in NFPA 13 22.4.4.7, FPH pg 15-56

33A Pressure Due to Elevation

P = 0.433H

P = psi

H = Height (ft)

34 ISO Water Supply Equation

(Green book pg 204; FPH pgs 15-24)

$NFF_i = (C_i)(O_i)(1 + (X_i + P_i))$

NFF ≡ Needed Fire Flow

C_i ≡ Construction Factor (FPH pg 15-25)

O ≡ Occupancy Factor (FPH pg 15-25 Table 15.2.1)

1 + (X+P) ≡ Exposure factor (FPH pg 15-27 Table 15.2.3) with a maximum value of 1.6. Note exceptions where X or P is equal to 0 due to building construction or occupancy classification.

$C_i = 18f\sqrt{A}$

f ≡ Coefficient related to class of construction (FPH pgs 15-25)

A ≡ Effective building area

For wood roofs of building **or** exposure building, add 500 gpm to total.

Round C_i to nearest 250 gpm **before** calculating NFF

Round final calc to **nearest** 250 gpm if under 2500 gpm and to **nearest** 500 gpm if over 2500 gpm

35 ISU (Iowa State) Water Supply Equation

(Green book pg 205; FPH pg15-25)

$RFF = V/100$

RFF ≡ Required Fire Flow

V ≡ Enclosed volume (ft^3)

36 IIU (Illinois Institute) Water Supply Equation

(Green book pg 205; FPH pg 15-26)

Residential Occupancies

$Flow = 9 \times 10^{-5}A^2 + 50 \times 10^{-2}A$

Non-residential Occupancies

$Flow = -1.3 \times 10^{-5}A^2 + 42 \times 10^{-2}A$

A ≡ Area of the fire (ft^2)

37 Door Opening Forces

(HFPE pg 4-281)

$$F = F_{DC} + \frac{k_d W A \Delta P}{2(W - d)}$$

F ≡ Total door opening force (lb) [N]

F_{DC} ≡ Force to overcome the door closer (lb) [N]

W ≡ Door width (ft) [m]

A ≡ Door area (ft^2) [m^2]

ΔP ≡ Pressure difference across door (in H_2O) [Pa]

d ≡ Distance from doorknob to the edge of the knob side of the door (ft) [m]

k_d ≡ Coefficient (5.20) [1.00]

38 Thrust Blocks

(NFPA A.10.8.2)

The required block area (A_b) is as follows:

$$A_b = (h)(b) = \frac{T(S_f)}{S_b}$$

where:

A_b = required block area (ft^2)
h = block height (ft)
b = calculated block width (ft)
T = thrust force (lbf)
S_f = safety factor (usually 1.5)
S_b = bearing strength (lb/ft^2)

Then, for a horizontal bend, the following formula is used:

$$b = \frac{2(S_f)(P)(A)\sin\left(\frac{\theta}{2}\right)}{(h)(S_b)}$$

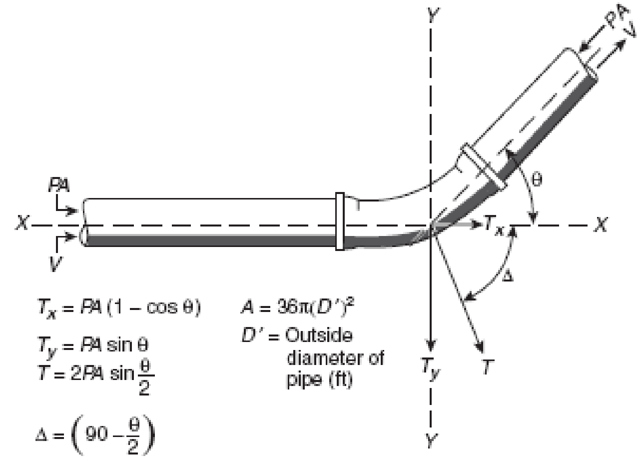
where:

b = calculated block width (ft)
S_f = safety factor (usually 1.5 for thrust block design)
P = water pressure (lb/in.^{2})
A = cross-sectional area of the pipe based on outside diameter
h = block height (ft)
S_b = horizontal bearing strength of the soil (lb/ft^2) (in.^{2})

Table A.10.8.2(b) Horizontal Bearing Strengths

	Bearing Strength (S_b)	
Soil	**lb/ft^2**	**kN/m^2**
Muck	0	0
Soft clay	1000	47.9
Silt	1500	71.8
Sandy silt	3000	143.6
Sand	4000	191.5
Sand clay	6000	287.3
Hard clay	9000	430.9

Note: Although the bearing strength values in this table have been used successfully in the design of thrust blocks and are considered to be conservative, their accuracy is totally dependent on accurate soil identification and evaluation. The ultimate responsibility for selecting the proper bearing strength of a particular soil type must rest with the design engineer.



T = Thrust force resulting from change in direction of flow (lbf)
T_x = Component of the thrust force acting parallel to the original direction of flow (lbf)
T_y = Component of the thrust force acting perpendicular to the original direction of flow (lbf)
P = Water pressure (psi^2)
A = Cross-sectional area of the pipe based on outside diameter (in.^{2})
V = Velocity in direction of flow

FIGURE A.10.8.2(a) Thrust Forces Acting on a Bend.

It can be easily shown that $T_y = PA \sin\theta$. The required volume of the block is as follows:

$$V_g = \frac{S_f PA \sin\theta}{W_m}$$

where:

V_g = block volume (ft^3)
S_f = safety factor
P = water pressure (psi)
A = cross-sectional area of the pipe interior
W_m = density of the block material (lb/ft^3)

In a case such as the one shown, the horizontal component of thrust force is calculated as follows:

$$T_x = PA(1 - \cos\theta)$$

where:

T_x = horizontal component of the thrust force
P = water pressure (psi)
A = cross-sectional area of the pipe interior

39 Reaction Forces in Nozzles

(Green book pg 262; FPH pgs 15-32 thru 34)

$F = 1.57c^2 d_2^2 p_2 (1 - \beta^2)$

F ≡ Reaction force (lb_f)

c ≡ Nozzle C-factor

d_2 ≡ Pipe diameter at point 2 (in)

p_2 ≡ Discharge velocity pressure (psi)

$\beta = {}^{d_2}/_{d_1}$

Simplified

$F = 1.57 p_1 d_2^2$ or $NF = 1.5 d^2 NP$

NF ≡ Nozzle force (lb_f)

NP ≡ Nozzle pressure (psi)

40 Rate of Heat Release

(Green book pg 391; NFPA 72 B.2.3.2.3.2; FPH pg 3-126)

$$Q = \alpha t^2$$

Q ≡ Rate of heat release (Btu/s) [kW]

α ≡ Fire intensity coefficient (Btu/s^3) [kW/s^2]

t ≡ Time after burning occurs (sec)

41 Heat Detector RTI

(Green book 390; NFPA 72 Table B.3.2.5 pg 72-202; FPH pg 3-126)

$$RTI = \tau_0 \sqrt{u_O}$$

RTI ≡ Response Time Index

τ_O ≡ Detector time constant (secs)

u_O ≡ Gas velocity (ft/sec) [m/sec]

42 Furnace Test Correction Factor

(Green book pg 482; NFPA 251 Table B.1)

$$C = \frac{2I(A - A_S)}{3(A_S + L)}$$

C ≡ Correction Factor

I ≡ Indicated fire resistance period

A ≡ Area under the curve of indicated average furnace temperature for the first three-fourths of the indicated period

A_S ≡ Area under the standard furnace curve for the same part of the indicated period. Found in NFPA 251 Table B.1 or Green book page 480-481

L ≡ Lag Correction (54°F-h or 3240°F-min)

Add C to A for final answer

43 Tied Fire Walls

(Green book pg 486; NFPA 221 A.5.4)

$$H = \frac{wBL^2}{8S}$$

H ≡ Horizontal pull per tie (lb)

w ≡ Dead load plus 25% of the live load of the roof (lb/ft^2)

B ≡ Distance between ties (ft)

L ≡ Span of the structural member running perpendicular to the wall (ft)

S ≡ Sag in ft that may be assumed as:

- 0.07L for open web steel trusses
- 0.09L for solid web steel beams
- 0.06L for wood trusses

44 Equivalent Thickness of Wall Material with Voids

(Green book pg 492)

$$T_E = {}^{V}/_{L(H)}$$

T_E ≡ Equivalent thickness (in)

V ≡ Net volume (gross volume less volume of voids) (in^3)

L ≡ Length of block (in)

H ≡ Height of block (in)

45 Wind Pressure

(Green book pg 419)

$$P_W = C_W K_w V^2$$

P_W ≡ Wind pressure (in. H_2O)

C_W ≡ Dimensionless pressure coefficient ranging from -0.8 to 0.8, with positive values for windward walls and negative values for leeward walls

K_W ≡ Coefficient, 4.82x10^{-4}

V ≡ Wind velocity (mph)

46 Stairwell Pressurization

(Green book pg 428; FPE pg 4-288)

$$\Delta P_{SB} = \Delta P_{SBb} + \frac{by}{1 + (\frac{A_{SB}}{A_{BO}})^2}$$

P=S+((B*Y)/(1+(A/O)^2)

ΔP_{SB} ≡ P ≡ Pressure difference between stairwell and building (inches of H_2O)

ΔP_{SBb} ≡ S ≡ Pressure difference between stairwell and building at the bottom of stairwell (inches H_2O)

A_{SB} ≡ A ≡ Flow area between stairwell and building (ft^2)

A_{BO} ≡ O ≡ Flow area between building and outside (ft^2)

y ≡ Y ≡ Distance above stairwell bottom

$$b = K_s \left(\frac{1}{T_O} - \frac{1}{T_S}\right)$$

B=K((1/T)-(1/S))

b ≡ B ≡ Temperature factor (in. H_2O/ft)

K_S ≡ K ≡ 7.64

T_O ≡ T ≡ Absolute temperature of outside air (°R)

T_S ≡ S ≡ Absolute temperature of stairwell air (°R)

$$Q = K_q \frac{NA_{SB}}{\sqrt{\rho}} \left(\frac{\Delta P_{SBt}^{3/2} - \Delta P_{SBb}^{3/2}}{\Delta P_{SBt} - \Delta P_{SBb}}\right)$$

Q=K*((N*A)/(P^(1/2))*((T^(3/2)-B^(3/2))/(T-B))

Q ≡ Flow rate of pressurization air (ft^3/min)

N ≡ Number of floors

A_{SB} ≡ A ≡ Flow area between the stairwell and building (ft^2)

ρ ≡ P ≡ Density of air (0.075 lb/ft^3)

ΔP_{SBb} ≡ B ≡ Pressure difference at the bottom of the stairwell (inches of H_2O)

ΔP_{SBt} ≡ T ≡ Pressure difference at top of stairwell (in. H_2O)

K_q ≡ 475

47 Stairwell Pressurization Height Limitation

(Green book pg 429)

$$H_m = K_m \frac{\Delta p_{max} - \Delta p_{min}}{\left(\frac{1}{T_O} - \frac{1}{T_B}\right)}\left[1 + \left(\frac{A_{SB}}{A_{SO}}\right)^2\right]$$

H=K*((M-N)/((1/O)-(1/B)))*((1+(A/S)^2))

H_m ≡ H ≡ Height limit (ft)

Δp_{max} ≡ M ≡ Maximum allowable pressure difference between the stairwell and the building (in. H_2O)

Δp_{min} ≡ N ≡ Minimum allowable pressure difference between the stairwell and the building (in. H_2O)

T_O ≡ O ≡ Absolute temperature of outside air (°R)

T_B ≡ B ≡ Absolute temperature of building air (°R)

A_{SB} ≡ A ≡ Flow area between the stairwell and the building (ft^2)

A_{SO} ≡ S ≡ Flow area between the building and outside (ft^2)

K_m ≡ K ≡ 0.131

48 Liquid Fuel Flame Height

(Green book pg 44; HFPE pg 3-274; HFPE pg 3-152)

$h = 0.235Q_c{}^{2/5} - 1.02D$

$H = 0.235(Q\text{^}(2/5) - (1.02*D)$

h ≡ Flame height

Q_c ≡ **Total** heat release rate of fire

D ≡ Diameter of fire

Note: 0.235 is an <u>average</u>. See HFPE pg 2-3 for values of materials. (i.e. gasoline is 0.200)

Note: Equivalent diameter for non-circular shapes: D = $\sqrt{4A/\pi}$ if L/w ~ 1.

49 Plume Centerline Temperature Rise

(Green book pg 144; HFPE pg 2-6; FPH pg 3-154; NFPA 92B Annex A pg 25)

$$\Delta T_O = 9.1\left(\frac{T_\infty}{g * c_p^2 \rho_\infty^2}\right)^{\frac{1}{3}} Q_c^{\frac{2}{3}} (z - z_o)^{5/3}$$

$\Delta T_O = T_O - T_\infty$

ΔT_O ≡ Temperature rise on centerline (K)

T_O ≡ Centerline Temperature (K)

T_∞ ≡ Ambient temperature (K) ≡ 273.16 K

g ≡ Gravity ≡ 9.81 m/s^2

c_p ≡ Specific heat of air at constant pressure ≡ 1 kJ/kg K

ρ_∞ ≡ Ambient density ≡ 1.2 kg/m^3

Factor to 9.1 $()^{1/3}$ = 25.0 K $m^{5/3}$ $kW^{-2/3}$

Q_c ≡ Convective heat release rate (kW)

z ≡ Elevation of Interest

z_0 ≡ Virtual Origin = $-1.02D+0.083Q^{2/5}$

D ≡ Effective Diameter (m)

Q ≡ **Total** Heat Release Rate (kW)

49A Temperature of Smoke in a Plume

(Green book pg 144; HFPE pg 2-6; FPH pg 3-154; NFPA 92B Annex A pg 25)

$T = T_\infty + Q_c^{0.6}/Mc_p$

T ≡ Temperature of Smoke in Plume (F)

T_∞ ≡ Ambient temperature (F)

Q_c ≡ Convective heat release rate (kW or Btu/s)

M ≡ Mass Flow Rate of Plume (kW/s or lb/s)

c_p ≡ Specific heat of air at constant pressure (1 kJ/kg-K or 0.24 Btu/lb-°F)

50 Plume Radius to point where temperature rise has declined to $0.5\Delta T_O$

(Green book pg 144; HFPE pg 2-6; FPH pg 3-154)

$$b_{\Delta T} = 0.12\left(\frac{T_O}{T_\infty}\right)^{\frac{1}{2}} (z - z_O)$$

$b_{\Delta T}$ ≡ Plume radius (m)

T_O ≡ Centerline Temperature (K)

T_∞ ≡ Ambient temperature (K) ≡ 293 K

z ≡ Elevation above fire source

z_O ≡ Elevation of virtual origin (m)

51 Plume Centerline Velocity

(Green book pg 144; HFPE pg 2-6; FPH pg 3-154)

$$u_O = 3.4\left(\frac{g}{c_\rho \rho_\infty T_\infty}\right)^{1/3} Q_c^{\frac{1}{3}} (z - z_o)^{-1/3}$$

U_O ≡ Mean Axial Velocity

Factor to $3.4()^{1/3}$ = 1.03 $m^{4/3}s^{-1}kW^{-1/3}$

Q_c ≡ Convective heat release rate (kW)

g ≡ Gravity ≡ 9.81 m/s^2

T_∞ ≡ Ambient temperature (K) ≡ 273.16 K

c_p ≡ Specific heat of air at constant pressure ≡ 1 kJ/kg K

ρ_∞ ≡ Ambient density ≡ 1.18 kg/m^3

z_0 ≡ Virtual Origin

z ≡ Elevation of Interest

52 Weak Plume Driven Temperature of Ceiling Jet

(Green book Answer Manual pg 17; HFPE pg 2-19)

$T_{max} - T_\infty = 16.9 \frac{Q_c{}^{2/3}}{H^{5/3}}$ for r/H <= 0.18

$T_{max} - T_\infty = 5.38 \frac{(Q_c/r)^{2/3}}{H}$ for r/H > 0.18

T_{max} ≡ Maximum temperature (°C)

T_∞ ≡ Ambient temperature (°C)

Q ≡ Either convective or total heat release rate (kW)

H ≡ Distance from fire source to the ceiling (m)

r ≡ Radial distance from plume centerline (m)

52A Weak Plume Driven Velocity of Ceiling Jet

(HFPE pg 2-19; FPH 3-160)

$U_{Plume} = 0.96 \left(\frac{Q_c}{H}\right)^{\frac{1}{3}}$ for r/H <= 0.15

$U_{Jet} = 0.195 \frac{(Q_c/_H)^{1/3}}{(r/_H)^{5/6}}$ for r/H > 0.18

U_{Plume} ≡ Maximum ceiling jet gas velocity near the plume impingement point (m/s)

U_{Jet} ≡ Maximum ceiling jet gas velocity (m/s)

Q ≡ Either convective or total heat release rate (kW)

H ≡ Distance from fire source to the ceiling (m)

r ≡ Radial distance from plume centerline (m)

53 Height of 1st Indication of Smoke for Steady Fires

(Green book pg 438; NFPA 92B Eqn 6.1.2.1a)

$$\frac{z}{H} = 0.67 - 0.28 \ln\left(\frac{tQ^{1/3} \,/\, H^{4/3}}{A \,/\, H^2}\right)$$

Note: For SI Units, use 1.11 instead of 0.67

z ≡ Height of first indication of smoke above the base of the fire (ft)

H ≡ Ceiling height above the fire surface (ft)

t ≡ Time (sec)

Q ≡ Heat release rate from steady fire (Btu/s)

A ≡ Cross-sectional area (length*width) of the space being filled with smoke (ft^2) and A/H^2 is the aspect ratio

54 Height of First Indication of Smoke for Unsteady (or Growing) Fires

(NFPA 92B Eqn 6.1.2.2a)

$$\frac{z}{H} = 0.23\left(\frac{t}{{t_g}^{2/5} H^{4/5} \left(\frac{A}{H^2}\right)^{3/5}}\right)^{-1.45}$$

OR

$$t = {t_g}^{2/5} H^{4/5} \left(\frac{A}{H^2}\right)^{3/5} \sqrt[1.45]{\frac{0.23H}{z}}$$

Note: For SI Units, use 0.91 instead of 0.23

z ≡ Height of first indication of smoke above fire surface (ft)

H ≡ Ceiling height above the surface (ft)

t ≡ Time (sec)

t_g ≡ Growth Time (sec) (time for fire to reach 1000 Btu/s or 1055 kW)

A ≡ Cross-sectional area of smoke filled space (ft^2)

55 Height of Flame Tip

(Green book pg 439; NFPA 92B Eqn 6.2.1.1a)

$$z_l = 0.533 Q_c^{\frac{2}{5}}$$

z_l ≡ Limiting elevation (ft)

Q_c ≡ Convection portion of heat release rate (Btu/sec)

56 Mass Flow Rate if H > z_l

(Green book pg 440; NFPA 92B Eqn 6.2.1.1b)

$$m = \left[0.022 Q_c^{\frac{1}{3}} z^{\frac{5}{3}}\right] + 0.0042 Q_c$$

m ≡ Mass flow rate of plume at height z (lb/sec)

Q_c ≡ Convection portion of heat release rate (Btu/sec)

z ≡ Height **above** the fuel (ft)

57 Volumetric Flow Rate

(Green book pg 440; NFPA 92B Eqn 6.4a)

$$V = {}^{60m}/_{\rho}$$

V ≡ Volumetric flow rate (ft^3/min)

m ≡ Mass flow rate of plume at height z (lb/sec)

ρ ≡ P ≡ Density of air (0.075 lb/ft^3)

58 Density of Smoke

(Green book pg 440; NFPA 92B Eqn 6.5a)

$$\frac{\rho}{\rho_o} = \frac{528}{460 + T}$$

(P/O)=528/(460+T)

ρ_o ≡ O ≡ Density of air (0.075 lb/ft^3)

ρ ≡ P ≡ Density of smoke at Temperature T(lb/ft^3)

T ≡ Temperature of smoke (°F)

59 Average Temperature of Fire Plume

(Green book pg 440; NFPA 92B Eqn 6.5a)

$$T_p = T_o + \frac{Q_c}{mC_p}$$

P=T+(Q/(m*C))

T_p ≡ P ≡ Average plume temperature at elevation z (°F)

T_o ≡ T ≡ Ambient temperature (°F)

Q_c ≡ Q ≡ Convection portion of heat release rate (Btu/sec)

m ≡ Mass flow rate of plume at height z (lb/sec)

C_p ≡ C ≡ Specific heat of plume gases (0.24 Btu/lb-°F)

60 Average Mass Flow Rate of Fire Plume

(Green book pg 442; FPH pg 18-65)

$$m_p = \left(\frac{\rho_o^2 g}{2}\right)^{1/2} A_v d^{1/2}$$

M=((P^2*G)/2)^1/2*A*D^(1/2)

m_p ≡ M ≡ Mass flow rate of the plume (lb/sec)

ρ_o ≡ P ≡ Density of air (0.075 lb/ft^3)

g ≡ Acceleration of gravity (32.2 ft/sec^2)

A_v ≡ A ≡ Aerodynamic vent area (ft^2)

d ≡ Depth of the smoke layer (ft)

61 Maximum Flow Rate to Avoid Plugholing

(Green book Answer Manual pg 63; NFPA 92B 6.3)

$$m_{max} = 0.354\beta d^{5/2}\left[\frac{T_s - T_o}{T_s}\right]^{1/2}\left[\frac{T_o}{T_s}\right]^{1/2}$$

m_{max} ≡ Maximum mass rate of exhaust without plugholing (lb/sec)

β ≡ Exhaust location (Dimensionless)

d ≡ Depth of smoke layer below the exhaust inlet (ft)

T_s ≡ Absolute temperature of smoke layer (°R)

T_o ≡ Absolute temperature of ambient layer (°R)

This equation is no longer in NFPA 92B. NFPA 92B now gives equation for volumetric flow rate

$$V_{max} = 452\gamma d^{5/2}\left(\frac{T_s - T_o}{T_o}\right)^{1/2}$$

V=452*G*D^(5/2)*((S-O)/O)^(1/2)

V_{max} ≡ V ≡ Maximum volumetric flow rate without plugholing at T_s (ft^3/min)

γ ≡ G ≡ Exhaust location factor (Per NFPA 92B 6.3.4 thru 6.3.6 γ is: 1 for exhaust inlets centered no closer than twice the diameter from the nearest wall; 0.5 for exhaust inlets centered less than twice the diameter from the nearest wall; 0.5 for exhaust inlets on a wall

d ≡ Depth of smoke layer below the lowest point of the exhaust inlet (ft)

T_s ≡ S ≡ Absolute temperature of smoke layer (R)

T_o ≡ O ≡ Absolute temperature of ambient layer (R)

62 Required Opposed Airflow for Smoke Control

(Green book Answer Manual pg 64; NFPA 92B Eqn 5.5.1)

$$v_e = 38\left(gH\frac{\{T_f + 460\} - \{T_o + 460\}}{\{T_f + 460\}}\right)^{1/2}$$

V=38*((G*H*(((F+460)-(O+460))/(F+460)))^(1/2)

v_e ≡ V ≡ Limiting air velocity (ft/min)

g ≡ Acceleration of gravity (32.2 ft/sec^2)

H ≡ Height of the opening as measured from the bottom of the opening (ft)

T_f ≡ F ≡ Temperature of heated smoke (°F) (Converted to R)

T_o ≡ O ≡ Temperature of ambient air (°F) (Converted to R)

63 Limiting Average Velocity through Communicating Space

(Green book Answer Manual pg 64; NFPA 92B Eqn 5.5.2)

$$v_e = 17\left({}^{Q}/_{z}\right)^{1/3}$$

v_e ≡ V ≡ Limiting air velocity (ft/min)

Q ≡ Heat release rate of fire (Btu/sec)

z ≡ Distance above the base of the fire to the bottom of the opening (ft)

64 Vented Fire Smoke Layer Temperature Change

(Green book Answer Manual pg 64; NFPA 92B Table G1.3)

$$\Delta T = [60(1 - x_1)Q_c]/(\rho_o c_p V)$$

T=(60*(1-X)*Q)/(P*C*V)

ΔT ≡ T ≡ Temperature rise in smoke layer (°F)

x_1 ≡ X ≡ Total heat loss factor from smoke layer to atrium boundaries (assume maximum temperature rise will occur ∴ $x_1 = 0$

Q_c ≡ Q ≡ 0.7Q ≡ Convective heat release rate (Btu/sec)

ρ_o ≡ P ≡ Density of ambient air (0.075 lb/ft^3)

c_p ≡ C≡ Specific heat of ambient air (0.241 Btu/lb-°F)

V ≡ Volumetric vent rate (ft^3/min)

65 Atrium ASET

(HFPE pgs 4-297&298)

$$z/H = 0.91\left[t * t_g^{-2/5} * H^{-4/5} * (\frac{A}{H^2})^{-3/5}\right]^{-1.45}$$

$$(z \div H) = 0.91\left(T * \left((G)^{-\frac{2}{5}}\right) * \left(H^{-\frac{4}{5}}\right) * \left(\frac{A}{H^2}\right)^{-\frac{3}{5}}\right)^{-1.45}$$

t ≡ time (s)

t_g (g) ≡ time growth (s) NFPA 92 Annex C

H ≡ Atrium Height (m or ft)

A ≡ Atrium Area (m^2 or ft^2)

z ≡ Critical layer height (m or ft)

66 Smoke Flow Across an Opening /Pressurization

(Green book pg 422; HFPE pg 4-280)

$$V = CA\sqrt{\frac{2\Delta P}{\rho}}$$

V ≡ Volumetric Airflow Rate (CFM)

C ≡ Flow coefficient (0.65)

A ≡ Flow area (also leakage area) (ft^2)

ΔP ≡ Pressure difference across flow path (in H_2O)

ρ ≡ Density of air entering the flow path (lb/ft^3)

$$V = K_f A\sqrt{\Delta P}$$

V ≡ Volumetric Airflow Rate (CFM)

K_f ≡ Flow coefficient (2610)

A ≡ Flow area (ft^2)

ΔP ≡ Pressure difference across flow path (in H_2O)

67 Stack Effect/Bouyancy

(Green book pg 417,418; HFPE pg 4-274,276)

$$\Delta P = K_S\left(\frac{1}{T_O} - \frac{1}{T_I}\right)h$$

ΔP ≡ Pressure difference (in H_2O)

K_S ≡ Coefficient (7.64) [3460]

T_O ≡ **Absolute** temperature of outside air (R) [K]

T_I ≡ **Absolute** temperature of inside air (R) [K]

h ≡ Distance above neutral plane (ft) [m]

68 Critical Airflow Velocity for Smoke Control

(HFPE pg 4-279)

$V_K = K_V(\frac{Q}{W})^{1/3}$

V_K ≡ Critical air velocity to prevent smoke backflow (fpm) [m/s]

Q ≡ Heat release rate into corridor (Btu/s) [kW]

W ≡ Corridor width (ft) [m]

K_V ≡ Coefficient (86.9) [0.292]

69 Minimum Recommended Vent Area for Venting of Low-strength Enclosures from Gases, Gas Mixtures and Mists

(Green book pg 465; NFPA 68 7.2.2; FPH pg 18-84)

$A_v = \frac{C(A_s)}{(P_{red})^{1/2}}$

V=((C*S)/(R^(1/2))

A_v ≡ V ≡ Minimum recommended vent area (sq ft)

C ≡ Fuel constant or venting parameter ($psi^{1/2}$) [Can be found in NFPA 68 7.2.2.1]

A_s ≡ S ≡ Internal surface area of enclosure including floor, roof and all walls (sq ft)

P_{red} ≡ R ≡ Maximum pressure to be attained during vented deflagration (psi)

For $PSI^{1/2}$

$C = (6.1x10^{-5})(S_u^2) + (6.1x10^{-4})(S_u) + 0.0416$

C=(6.1x10^-5)*(S^2)+(6.1x10^-4)*(S)+0.0416

For $bar^{1/2}$

$C = (1.57x10^{-5})(S_u^2) + (1.57x10^{-4})(S_u + 0.0109)$

C=(1.57x10^-5)*(S^2)+(1.57x10^-4)*(S)+0.0109

C ≡ Fuel constant or venting parameter ($psi^{1/2}$) [Can be found in NFPA 68 7.2.2.1]

S_u ≡ S ≡ Fuel fundamental burning velocity (cm/s) [Has to be less than 60 cm/s. Can be found in NFPA 68 Table D.1(a) pg 68-61 or FPH Table 18.6.3 pg 18-82]

70 Beam or Column Substitution

(Green book pg 495; SFPE 4-220)

$h_1 = \left(\frac{W_2/D_2 + 0.6}{W_1/D_1 + 0.6}\right)h_2$

h ≡ Thickness of spray-applied fire protection (in)

W ≡ Weight of steel beam (lb/ft)

D ≡ Heated perimeter of steel beam (see Fig. 4-9.11 SFPE 4-220)

1 ≡ Substitute beam and required protection thickness

2 ≡ The beam and protection thickness specified in the referenced tested design or tested assembly

71 Venting One End of Elongated Enclosure

(Green book pg 466; NFPA 68 7.2.3.3)

$L_3 \leq 12\ A/p$

L_3 ≡ Longest dimension of the enclosure (ft)

A ≡ Cross-sectional area through which the burning mixture must vent (ft^2)

p ≡ Perimeter of that cross section (ft)

For highly turbulent gas mixtures, the length to diameter ratio should not exceed 2:

$L_3 \leq 8\ A/p$ (NFPA 68 7.2.3.4

72 Minimum P_{red} for Non-Relieving Wall Construction

(Green book pg 466; NFPA 68 7.2.6.1)

$Minimum\ P_{red} = P_{stat} + 0.024\ bar\ (or\ 50\ psf\ or\ 0.35\ psig)$

73 Vent Area for High-Strength Enclosures

(Green book pg 467; NFPA 68 7.3; FPH 18-85)

$D = 2(\frac{A^*}{\pi})^{1/2}$

D ≡ Equivalent diameter (ft)

A^* ≡ Cross-sectional area <u>normal</u> to the longest dimension (ft^2)

For L/D≤2 and volume≤1000 m^3, then

$A_v = [(0.127 \log_{10} K_G - 0.0567)P_{red}^{-0.582} + 0.175P_{red}^{-0.572}(P_{stat} - 0.1)]V^{2/3}$

A=(((0.127*log(K)-0.0567)*R^(-0.582))+((0.175*R^(-0.572))*(S-0.1)))*V^(2/3)

A_v ≡ A ≡ Vent area (m^2)

K_G ≡ K ≡Deflagration index of gas (bar-m/sec)≤550

P_{red} ≡ R ≡ 2 bar and at least 0.05 bar greater than P_{stat}

P_{stat} ≡ S ≤ 0.5 bar

V ≡ Enclosure volume (m^3)

If L/D between 2 and 5 and P_{red} is no greater than 2.0 bar, additional vent area must be added to A_v

$\Delta A = \frac{A_v K_G[(L/D) - 2]^2}{750}$

X=((A*K*(((L/D)-2)^2)/750

Final $A_v = \Delta A + A_v$

74 Effects of Vent Ducts (Non-cubical Vessels)

(Green book pg 468 & 471; NFPA 68 7.4.3.3 and 7.4.3.4)

$If\ L < 3\ m\ \therefore\ P'_{red} = 0.779(P_{red})^{1.161}$

$If\ L > 3\ m\ \therefore\ P'_{red} = 0.172(P_{red})^{1.963}$

75 Effects of Vent Ducts (Cubical Vessels)

(Green book pg 471;)

$$\frac{P''_{red}}{P_{red}} = 1 + \left[17.3\left(\frac{A_v}{V^{0.753}}\right)^{1.6}\frac{L}{D}\right]$$

P/R=1+(((17.3*((A/(V^0.753))^1.6))*(L/D))

P''_{red} ≡ P ≡ Pressure during a vented deflagration with the vent duct in place (bar)

P_{red} ≡ R ≡ Pressure during a vented deflagration without the vent duct (bar)

A_v ≡ A ≡ Vent area (m^2)

V ≡ Enclosure volume (m^3)

L ≡ Duct length (m)

D ≡ Equivalent diameter of the vent duct (m)

76 Venting of Deflagrations of Dusts and Hybrid Mixtures

(Green book pg 469; NFPA 68 8.2.2; FPH pg 18-86)

$$A_{v0} = .0001\left(1 + 1.54P_{stat}^{\frac{4}{3}}\right)K_{st}V^{\frac{3}{4}}\sqrt{\frac{P_{max}}{P_{red}} - 1}$$

O=(0.0001)*(1+1.54*(S^(4/3)))*K*(V^(3/4))*SQRT(M/R-1)

A_{v0} ≡ O ≡ Vent area (m^2)

P_{stat} ≡ S ≡ Nominal static burst pressure of vent (bar)

K_{st} ≡ K ≡ Deflagration index (bar-m/sec)

V ≡ Enclosure volume (m^3)

P_{max} ≡ M ≡ Maximum pressure of deflagration (bar)

P_{red} ≡ R ≡ Reduced pressure after deflagration (bar)

Equation is valid for the following:

1) 5 bar ≤ P_{max} ≤ 12 bar
2) 10 bar-m/sec ≤ K_{st} ≤ 800 bar-m/sec
3) 0.1 m^3 ≤ V ≤ 10,000 m^3
4) P_{stat} ≤ 0.75 bar

When L/D is ≤ 2, A_{v1} shall be set equal to A_{v0}

For 2 ≤ L/D ≤ 6, A_{v1} shall be calculated as:

$$A_{v1} = A_{v0}\left[1 + 0.6\left(\frac{L}{D} - 2\right)^{0.75}\exp\left(-0.95P_{red}^2\right)\right]$$

A=O*((1+0.6*(L/D-2)^0.75)*exp(-0.95*R^2))

77 Partial Volume Deflagrations

(Green book pg 470; NFPA 68 8.3; FPH pg 18-86)

$$A_{vpv} = A_{v0}X_r^{-1/3}\left[\frac{\left(X_r - \frac{P_{red}}{P_{max}}\right)}{\left(1 - \frac{P_{red}}{P_{max}}\right)}\right]^{1/2}$$

V = A*(X^-1/3)*((X-(R/M)/(1-R/M))^(1/2)

A_{vpv} ≡ Required vent area for the PVD (m^2)

A_{v0} ≡ Required vent area for the entire enclosure if filled with an ignitable mixture (m^2)

X_r ≡ Fill fraction at the time of the PVD

P_{max} ≡ Maximum pressure of deflagration (bar)

P_{red} ≡ Reduced pressure after deflagration (bar)

Π ≡ P_{red}/P_{max}

78 Column Resistive Rating

(Green book pg 495; FPH pg 18-86)

$R = [C_1(W/D) + C_2]h$

R ≡ Fire resistance period (min)

C_1 and C_2 ≡ Material dependent constants determined by ASTM E119 test

W ≡ Mass of steel shape (lbs/ft)

D ≡ Heated perimeter of column (in) from Green book pg 494 (remember to use 3 sides for beam and 4 sides for column)

h ≡ Thickness of the coating (in)

79 Vent Area Threshold Mass

(NFPA 68 Equation 8.2.7.2)

$$M_T = \left[6.67(P_{red}^2)(n^{0.3})\left(\frac{V}{K_{St}^{0.5}}\right)\right]^{1.67}$$

T=((6.67*(R^2)*(N^0.3)*((V/(K^(0.5)))))^1.67

M_T ≡ T ≡ Threshold mass (kg/m^2)

P_{red} ≡ R ≡ Reduced pressure after deflagration (bar)

n ≡ N ≡ Number of panels

V ≡ Enclosure volume (m^3)

K_{st} ≡ K ≡ Deflagration index (bar-m/sec)

80 Time Value of Money

$$P\left(\frac{1 - \left(1 + {}^{I}/_{100}\right)^{-N}}{{}^{I}/_{100}}\right) + F_v\left(1 + {}^{I}/_{100}\right)^{-N} + P_v = 0$$

P ≡ Payment

F_v ≡ Future Value

P_v ≡ Present Value

I ≡ Interest Rate (%)

Note: This will yield negative numbers for at least one result due to that number being a value that is paid.

Heat Release Rates HFPE pg 3-10 thru 3-32

- Also NFPA 92B Annex B and NFPA 72 Annex B-2

- 5 kW/ m^2 for a person to get burned in 13 sec on bare skin, 40 sec for 2nd degree burn (HFPE pg 3-310 & 3-309)
- Skin Burns (HFPE pg 2-129 & 3-308)
  - 1st Degree 1.33-1.667 kW/m^2 (41.8 kJ/m^2)
  - 2nd Degree 4-12.17 kW/m^2 (83.6 kJ/m^2)
  - 3rd Degree 16.67 kW/ m^2 (162.2 kJ/m^2)

- NFPA 92B pg 38 Annex C for T^2 fire growth rates
  - Ultra Fast $t_g = 75$
  - Fast $t_g = 150$
  - Medium $t_g = 300$
  - Slow $t_g = 600$
  - Also see Green book pg 102 for T^2 fires

Flashover is at 20 kW/m^2 or 500 - 600°C (FPH 3-150)

- See Green book pg 159 for Equivalent Fire Duration

ASET ≡ Available Safe Egress Time

RSET ≡ Required Safe Evacuation (Egress) Time

Fire Classes (NFPA 1 3.3.80; NFPA 1 13.6.5.2; NFPA 10.3.3):

- **Class A –** Fires in ordinary combustible materials, such as wood, cloth, paper, rubber and many plastics.
- **Class B –** Fires in flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols and flammable gases.
- **Class C –** Fires that involve energized electrical equipment.
- **Class D –** Fires in combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium.
- **Class K –** Fires in cooking appliances that involve combustible cooking media (vegetable or animal oils and fats).

Fire Pumps:

- Can be rated at 150% of flow capacity @ 65% of rated head (NFPA 20 5.8.1 & 6.2)
  - Green book pg 213
  - FPH 15-85 through 15-103

- NFPA 20 A.14.2.7(4) for fire pump controller operation

- NFPA 20 A11.4.3.1 fuel for 8 hrs operation
- NFPA 20 11.2.2.4 & 11.2.2.5 for diesel fuel tank capacity

- NFPA 220 for Types of Construction

- NFPA 24 for Thrust Blocks, Flushing, Backflow Prevention 10.8.1.1; 10.8.2; A.10.8.1.1

- Fire Hydrant Marking is found in NFPA 291 or Annex D of NFPA 24 pg 24-25

Sprinkler Systems:

1. Determine sprinkler density per occupancy hazard classification
2. Add hose demand
3. If dry pipe system, add 30% to required area (NFPA 13 11.2.3.2.5)
4. Make adjustment for storage height
5. Make adjustments if high temperature heads are used (NFPA 13 11.2.3.2.6)
6. From type of sprinkler, determine maximum area of sprinkler head and spacing
7. Use NFPA 30, 30B and 409 for special occupancies
8. Number of sprinklers on a branch = $\frac{1.2\sqrt{Sprinkle\ Area}}{Distance\ between\ heads}$
9. Make adjustments for QR heads (NFPA 13 11.2.3.2.3)

Fire Alarm (NFPA 72):

A. Supervisory Signals – Green book pg 384
B. Trouble Signals – Green book pg 385
C. Off-Premises Monitoring – Green book pg 385

Class A circuits are more reliable since it remains operational during a single open or single ground fault.

Class B circuits are less reliable since it remains only operational up to the location of the open fault.

IDC – Initiating Device Circuit (Green book pg 387)

NAC – Notification Appliance Circuits (Green book pg 387)

SLC – Signaling Line Circuits (Green book pg 387)

NFPA 72 5.6.5 for Spacing Requirements

Venting Deflagrations (NFPA 68):

- Green book pg 463
- Section 9.1.2 for distance between vents
- Section 9.2.6 recommends vent mass no greater than 12.2 kb/m^2 (2.5 lb/ft^2)
- Venting walls
  - Green book pg 464

1 W = 1J/s 1 kW = 1 kJ/s 1 MW = 1 MJ/s

Conversions:

- Rankin: $t_R = t_F + 459.69$
- Kelvin: $t_K = t_C + 273.16$
- Feet: 1 ft = 0.3048 m = 30.48 cm
- Meter: 1 m = 3.28084 ft
- Gallon: 1 Gallon = 3.785412 Liters
- Square Feet: 1 ft^2 = 0.092903 m^2
- Kilogram: 1 kg = 2.204623 lbs
- Kilowatts: 1 kW = 1055.87 Btu/s
- Psi: 1 psi =2.317 feet of head
- Feet of Head: 1 ft of hd = 0.433 psi

Water:

8.34 lbs/gal
7.48 gal/ft^3
62.4 lbs/ft^3

Volume of a pipe: $V = 0.25\pi D^2 L$

1 Pa (Pascal) = 1 N/m^2 = 1 J/m^3 = 1 kg/($m*s^2$)

Sound Pressure ≡ Pa; Sound Intensity ≡ W/m^2

Threshold of hearing ≡ 0 dB ≡ 0.00002 Pa ≡ 1 x 10^{-12} W/m^2 120dB = 20 Pa = 1 W/m^2

Egress/Behavior in Smoke
HFPE 3-315-379; FPH Chapter 4 (more up to date)

Evacuation Time Predictions
HFPE 3-354; FPH 4-58

Evacuation Speed of Disabled Persons
HFPE 3-360-361; FPH 4-39-42, 55-57