Calculation of Radiation Distances

Inputs:

Outside Diameter of Pipe	***D***	**450**	**mm**
Wall thickness (to determine D_i)*	t_w	**7.9**	**mm**
Pressure (choose kPa/MPa/Bar)	***P***	**2.73**	**MPa**

*leave wall thickness blank if unknown

Summary

Radiation contour for Full Bore Rupture:

Radiation contour: 12.6kW/m^2	$D_{12.6}$	**152**	**m**
Radiation contour: 4.7kW/m^2	$D_{4.7}$	**245**	**m**

Hole diameters in order to satisfy maximum heat release requirements:

Heat release in GJ/s	***Q***	**1**	**10**	**GJ/s**
Minimum hole diameter	***d***	**108**	**278**	**mm**

The mass flow rate w is calculated by

$$w = \rho q$$

where,

ρ = the density of the gas at upstream (pressurised conditions)

q = volume flow rate, given by,

$$q = YCA\sqrt{\frac{2\Delta P}{\rho}} \quad \text{... Crane, 1999 eqn 2 - 24}$$

where

Y, C = expansion and flow coefficients

A = hole cross - sectional area

ΔP = maximum (critical) pressure drop from upstream to downstream.

Then,

$$D = \sqrt{\frac{\tau F Q}{4\pi K}} \quad \text{...API RP 521 eqn 20}$$

where,

D = the minimum distance from the source of radiation

F = fraction of heat transmitted

Q = heat release

K = allowable radiation (4.7 or 12.6 kw/m^2)

τ = fraction of heat intensity transmitted, given by,

$$\tau = 0.79\left(\frac{100}{r}\right)^{\frac{1}{16}}\left(\frac{30.5}{D}\right)^{\frac{1}{16}} \quad \text{... API RP 521 eqn C - 2}$$

where,

r = relative humidity

Pipe Constants			
Outside Diameter of Pipe	D	450	mm
Wall thickness	t_w	7.9	mm
Inside Diameter of Pipe	D_i	434.2	mm
Pressure	P	2.73	MPa
Pressure in pipeline in Bars	P	27.3	Bar

Other Constants				
Fraction of heat radiated	F	0.2		(API 521, Table 10)
Relative humidity	r	40	%	(Lower bound Ref Bureau of Meteorology)

Constants for Natural Gas[1]			
Gross Heating Value	H_C	40500	kJ/kg

Approx Density of Natural Gas	ρ_{atmos}	0.6283	kg/m^3	(at atmospheric conditions)
Density at upstream conditions	ρ	20.75	kg/m^3	
Approximate specific gravity	S_g	0.62		(relative to air)
Approximate Molecular Weight	M	18.2		$R = \frac{R_0}{M}$ where R_0 is the universal gas constant (8314 J/kg-mol K)
Individual gas constant	R	456.81	J/kg K	
Ratio of specific heats	γ	1.32		
Assumed temperature	$T_{°C}$	15	°C	
	T	288	K	

Calculations				
Critical pressure ratio[2]	r_c	0.5		
Maximum (critical) pressure drop	ΔP	1.365	MPa	$P(1-r_c)$

						Full Bore Rupture	
Hole diameter		3	50	30	95	434.2	mm
Hole diameter	d_2	0.003	0.05	0.03	0.095	0.4342	m
Ratio of diameters	β	0.01	0.12	0.07	0.22	1.00	$d_2 : D_i$
Hole area (assume circular hole)	A	0.000007	0.001963	0.000707	0.007088	0.148071	m^2
Expansion factor[3]	Y	0.6	0.6	0.6	0.6	0.6	
Flow coefficient (square-edged orifices)[4]	C	0.6	0.6	0.6	0.6	0.9	
Volume Flow rate	q	0.00092	0.26	0.09	0.93	29.00	m^3/s
Mass flow rate	w	0.02	5.32	1.92	19.21	601.81	kg/s
Heat release	Q	0.001	0.215	0.078	0.778	24.373	GJ/s or GW
Unadjusted 12.6kW/m[2] distance	$(D_{12.6})$	1	16	10	31	175	m
Unadjusted 4.7kW/m[2] distance	$(D_{4.7})$	2	27	16	51	287	m
Fraction of heat intensity transmitted	$\tau_{12.6}$	1.036	0.869	0.898	0.835	0.750	
	$\tau_{4.7}$	1.005	0.843	0.870	0.810	0.727	
Radiation contour: 12.6kW/m²	$D_{12.6}$	**1**	**15**	**9**	**29**	**152**	**m**
Radiation contour: 4.7kW/m²	$D_{4.7}$	**2**	**25**	**15**	**46**	**245**	**m**

In order to satisfy T1 and T2 maximum heat release requirements:

Heat release in GJ/s	*Q*	1	10	GJ/s
Minimum hole diameter	***d***	**107.7**	**278.1**	**mm**

Notes/references

1 Constants for Natural Gas. Reference: AGL Natural Gas Technical Data Book, 1996. Based on the following composition as % by volume: Methane 88.8, Ethane 7.8, Carbon Dioxide 1.9, Nitrogen 1.3, Propane 0.2, Butanes and Pentanes trace.

2 The Critical Pressure Ratio (r_C) is the largest ratio of downstream pressure to upstream pressure capable of producing sonic (critical) velocity in the gas (Crane, 1999 page A-22)

3 Reference Crane, 1999 page A-22.

4 Reference Crane, 1999 page A-20. The Flow Coefficient (C) for square edged orifices is a function of Reynolds number (R_e) and the ratio of orifice to upstream diameter (β). Gas discharged to atmosphere (at high velocity) will have a high R_e and flow will always be in the fully turbulent range, in which the flow factor is constant for each diameter ratio.