LARGE LNG FIRE THERMAL RADIATION

MODELING ISSUES & HAZARD CRITERIA REVISITED

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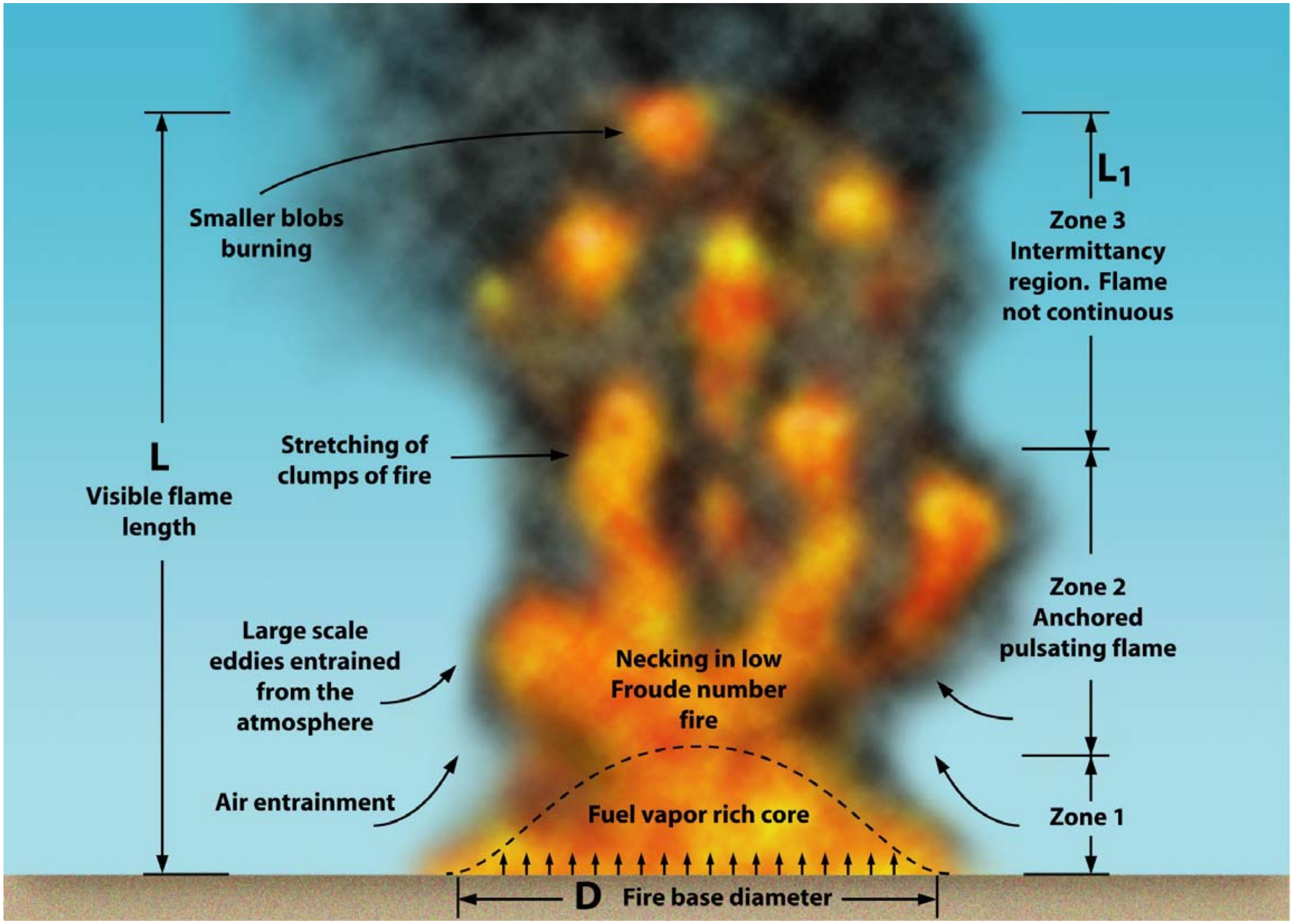
Introduction

- Compare, photographically, the characteristics of large (experimental) LNG fires and other hydrocarbon fires.
- Review the appropriate values to be used for various parameters used in thermal radiation calculations.
- Revisit the correlations used for fire size determination
- Propose a new diffusion LNG fire model which includes smoke effects
- Comment on common errors made in using the % energy radiation in the "point source thermal radiation model"
- Screen a 6 min film of the 35m diameter fire of the Montoir LNG tests.

15 m dia LNG Fire on Water

Similarities in burning characteristics in 35m dia LNG Pool Fire & an Oil Fire

Different Zones of Combustion in a Large Diffusion Fire



Fire Hazard Calculations

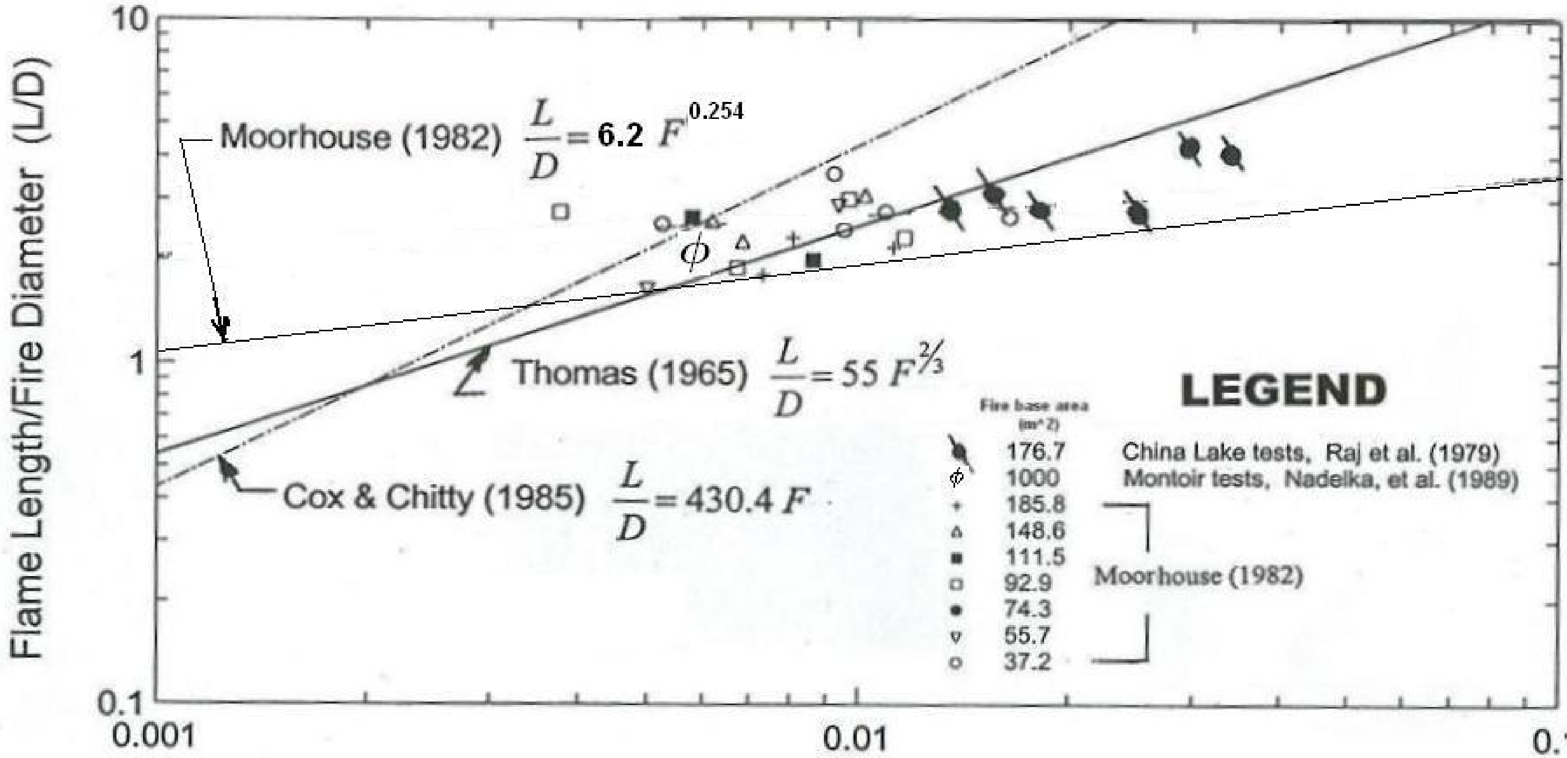
$$\dot{q}'' = E\,F\,\tau$$

$$E \equiv E(D,\ fuel\ characteristics, \frac{C}{H}, etc) = Emissive\ Power$$

$$F \equiv F(Fire\ geometry, receiver\ location \,\&\, orientation)$$

$$\tau \equiv \tau(RH, T_a, Fire\ emission\ spectrum) = Atmospheric\ transmissivity$$

Flame Height Correlation and Experimental Data



$F = \left[\frac{\dot{m}''}{\rho_a \sqrt{gD}}\right]$ = *Dimensionless burning rate or combustion Froude number*

Variation of Emissive Power with Fire Diameter

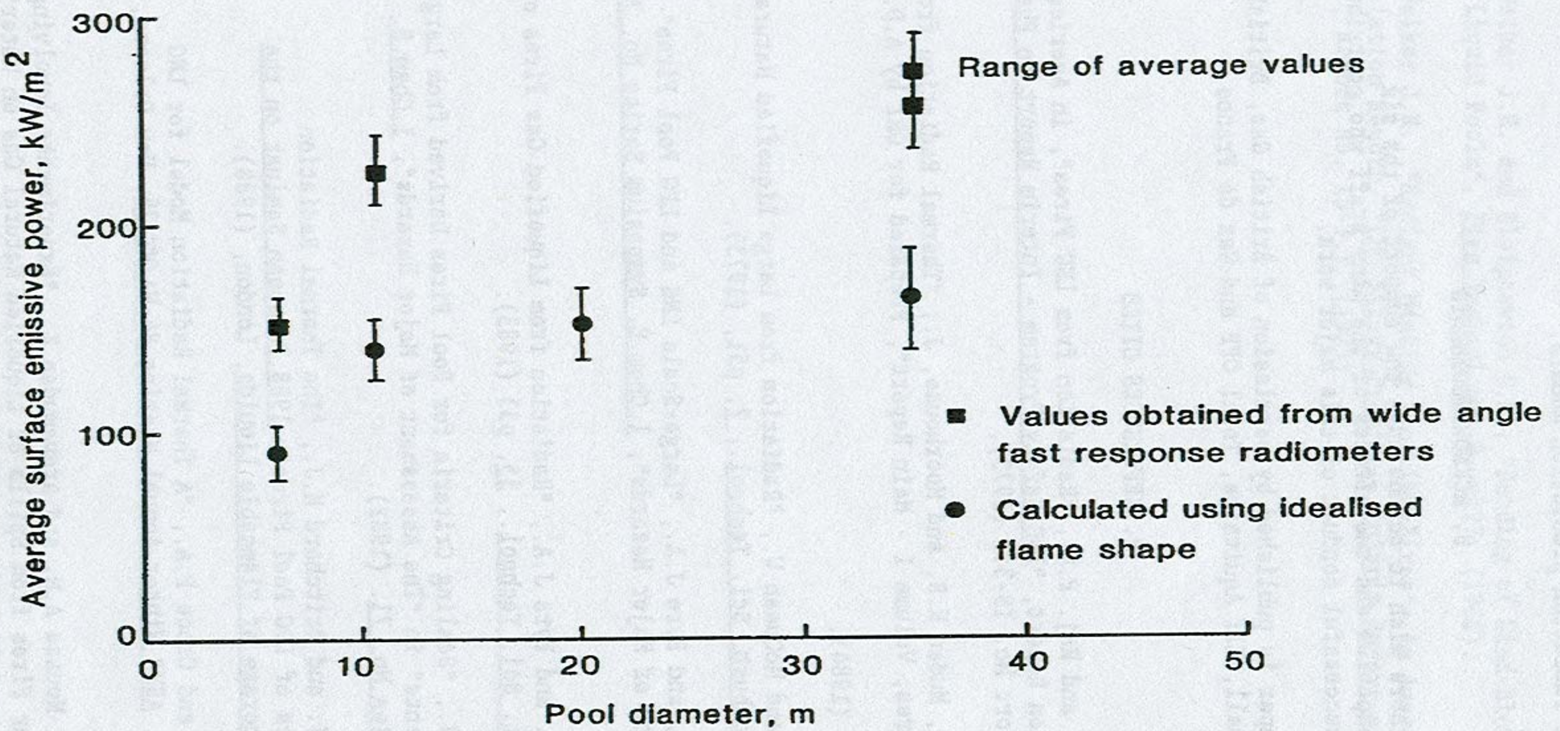


Figure 8. AVERAGE SURFACE EMISSIVE POWER VERSUS POOL DIAMETER

Source: Nedelka, et al. (1989)

Effect of Smoke on Radiation

Y = Mass of soot produced/Mass of fuel burned

$$\mathbf{Y = Y\{Fuel\ C/H, \phi, D, ?\}}$$

For Crude Oil fires (Notarianni, et al , 1993)

$$\mathbf{Y = 9.412 + 2.758 * \log_{10}(D)}; \quad \text{D in meters}$$

(about 13 % for 17 m dia fire)

- No field experimental data for LNG, propane or other large liquid fuel diffusion fires
- For laboratory propane diffusion flames, measured volume fraction of smoke is $2x10^{-2}$ ppm @ fuel/air volume concentration of $3x10^{-2}$ (Y value is of the order of 0.7 %!) [Sivathanu & Faeth, 1990]

Smoke Extinction of Radiation

- Transmissivity of smoke in a fire to thermal radiation is given by (SFPE, 2002)

$$\tau_S = Exp(-k_m\, C_S\, 0.63D)$$

k_m = Specific soot extinction area (m^2/kg)

= 130 for propane fires (McCaffrey, et al., 1988)

$$C_S = \rho_a Y \frac{1}{\left[1 + \frac{r}{\beta} + \frac{\Delta H_c}{C_a T_a}\right]}$$

Smoke Extinction of Radiation (cont'd)

Fire Diameter (m)	Soot mass yield (Y)* (%)	Soot Concentration (C_S) kg/m^3	Soot Transmissivity (τ_S)	Effective SEP in the soot region (E_{eff}) kW/m^2	Remarks
15	6.38	1.39 E-4	0.84	189.0	$k_m = 130\ m^2/kg$ $r = 17.17$ for CH_4
35	6.84	1.49 E-4	0.65	146.3	$1/\beta = 1/0.06 = 16.7$ $E = 225\ kW/m^2$
300	8.12	1.77 E-4	1.3E-2	2.9	$T_a = 293$ K

* Modified Notarianni correlation (1/2 of crude yield for CH_4)

Combustion Energy Fraction Radiated LNG Pool Fire on Water

$$\chi_R = \frac{\pi\, D\, L\, E}{(\pi/4)\, D^2\, \dot{m}''\, \Delta H_C} = 220\left(\frac{E}{\dot{m}''\, \Delta H_C}\right)\left[\frac{\dot{m}''}{\rho_a \sqrt{g\, D}}\right]^{\frac{2}{3}}$$

Pool Diameter (m)	**L/D**	χ_R (%)
15	3.6	21.0
35	2.7	15.8
300	1.3	7.6
E = 175 kW/m^2; ΔH_C = 50E6 J/kg; m”=0.24 kg/m^2 s		

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Conclusions

1) When using "solid flame" model for radiation hazard evaluation, the SEP used must correspond to flame height correlation from which it was developed.
2) Thomas' second correlation with 2/3 power relationship to dimensionless burning rate should be used for large fires of concern.
3) Caution should be exercised when using (χ_R) % emission as the basis of hazard assessment. It should be noted that $\chi \propto D^{-1/3}$, at the very least.

Conclusions (cont'd)

3) Burning dynamics and radiative output characteristics are similar in large pool fires of LNG and other higher hydrocarbon liquids.
4) Zoned "Solid Flame" model should be used for LNG fire radiation hazard assessment.
5) Effect of soot/smoke and the intermittency of combustion in higher layers should be considered.

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