Fire Dynamics
Fire plume II

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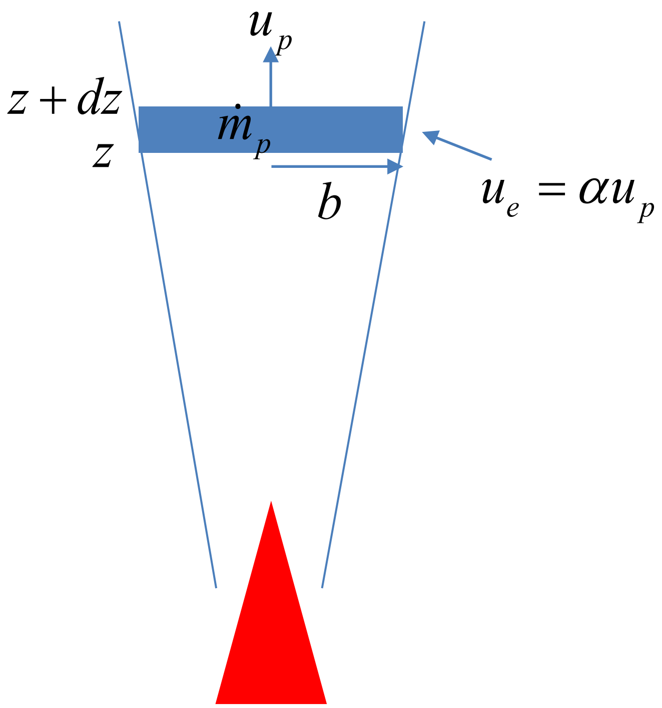
Objectives

- Calculating flame height of a pool fire

Ideal fire plume



$$u_p = 1.94 \left(\frac{g}{\rho_\infty c_p T_\infty} \right)^{1/3} \dot{Q}_c^{\,1/3} z^{-1/3}$$

$$\dot{m}_p = 0.2 \left(\frac{\rho_\infty^{\,2} g}{c_p T_\infty} \right)^{1/3} \dot{Q}_c^{\,1/3} z^{5/3}$$

$$\Delta T_p = 5.0 \left(\frac{T_\infty}{g c_p^{\,2} \rho_\infty^{\,2}} \right)^{1/3} \dot{Q}_c^{\,2/3} z^{-5/3}$$

Zukoski plume

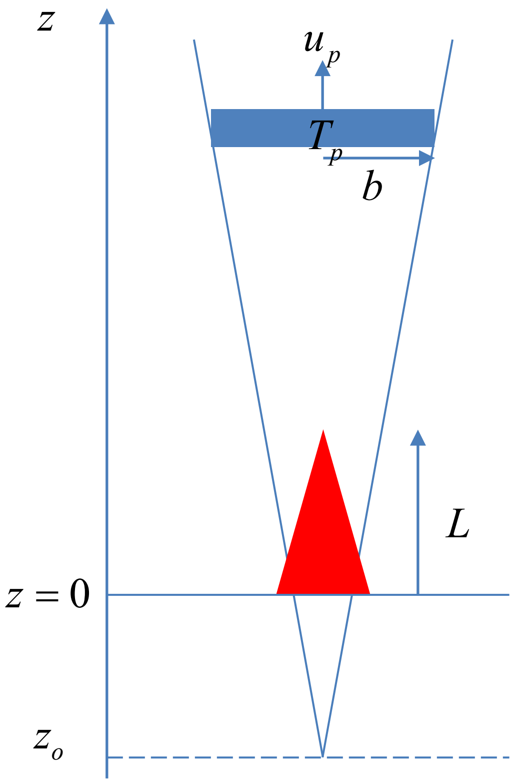
- Zukoski plume

$$\dot{m}_p = 0.21\left(\frac{\rho_\infty{}^2 g}{c_p T_\infty}\right)^{1/3} \dot{Q}_c{}^{1/3} z^{5/3} = 0.071\dot{Q}_c{}^{1/3} z^{5/3}$$

- Thomas plume for near-field
  - When diameter is larger than flame height

$$\dot{m}_p = 0.59 D z^{3/2}$$

Heskestad plume



Flame height: $L = 0.235\dot{Q}^{2/5} - 1.02D$

Virtual origin: $z_o = 0.083\dot{Q}^{2/5} - 1.02D$

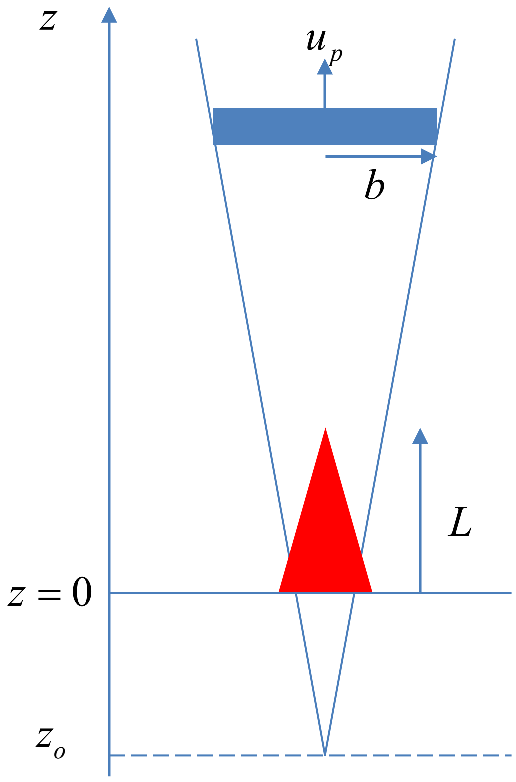
$\dot{Q}_c$[kW], and u_p[m/s]

$$b = 0.12\left(\frac{T_p}{T_a}\right)^{1/2}(z - z_o)$$

$$\Delta T_p = T_p - T_a \approx 25\left(\frac{\dot{Q}_c^{2/5}}{(z - z_o)}\right)^{5/3}$$

$$u_p \approx 1.0\left(\frac{\dot{Q}_c}{(z - z_o)}\right)^{1/3}$$

Heskestad plume



For z > L, $\dot{m}_p$[kg/s], $\dot{Q}_c[kW], L[m]$

$$\dot{m}_p = 0.071\dot{Q}_c^{1/3}\left(z-z_o\right)^{5/3} + (1.92\times10^{-3})\dot{Q}_c$$

For z < L,

$$\dot{m}_p = 0.0056\dot{Q}_c\left(\frac{z}{L}\right)$$

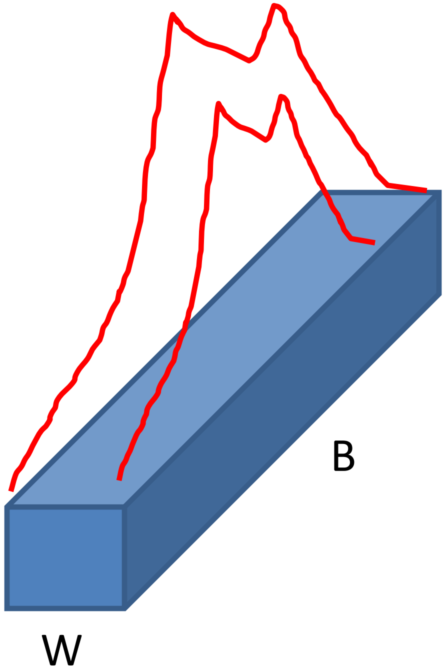
McCaffrey plume

Region	$z/\dot{Q}^{2/5}$ [m/kW$^{2/5}$]	η	κ
Continuous	< 0.08	1/2	6.8 [m$^{1/2}$/s]
Intermittent	0.08–0.2	0	1.9 [m/(kW$^{1/5}$s)]
Plume	> 0.2	–1/3	1.1 [m$^{4/4}$/(kW$^{1/3}$s)]

$$\Delta T_p = T_a \left(\frac{\kappa}{0.9\sqrt{2g}} \right)^2 \left(\frac{z}{\dot{Q}^{2/5}} \right)^{2\eta - 1}$$

$$u_p = \kappa \left(\frac{z}{\dot{Q}^{2/5}} \right)^{\eta} \dot{Q}^{1/5}$$

Line fire



For B > 3W,

$$L = 0.035\left(\frac{\dot{Q}}{B}\right)^{2/3}$$

Example

Calculate the flame height of heptane in a 1 m by 1 m pan.

	ΔH_c [kJ/g]	$\dot{m}''_\infty$ [kg/m^2-s]	$k\beta$ [1/m]	density [kg/m^3]
Butane	45.7	0.078	2.7	573
Benzene	40.1	0.085	2.7	874
Hexane	44.7	0.074	1.9	650
Heptane	44.6	0.101	1.1	675
Gasoline	43.7	0.055	2.1	740
Kerosene	43.2	0.039	3.5	820

Example

Equivalent diameter (D)

$$\frac{\pi D^2}{4} = (1)(1) \Rightarrow D = 1.13 \text{ m}$$

$$\dot{Q} = \Delta H_c \dot{m}_f = \Delta H_c \dot{m}'' A = \Delta H_c \dot{m}''_\infty (1 - e^{-k\beta D}) A$$

$$= (44600\ [\frac{kJ}{kg}])(0.101\ [\frac{kg}{m^2 s}])(1 - e^{-(1.1)(1.13)})(1\ m^2)$$

$$= 3205 \text{ kW}$$

$$L = 0.235\dot{Q}^{2/5} - 1.02D$$

$$= 0.235(3205)^{2/5} - 1.02(1.13) = 4.8\ m$$

Example 2

Calculate the average values of pool diameter of the hydrocarbon fuels in the table below that results in the flame height of 3 m (10 ft ceiling).

->Excel spreadsheet

	ΔH_c [kJ/g]	$\dot{m}''_\infty$ [kg/m^2-s]	$k\beta$ [1/m]	density [kg/m^3]
Butane	45.7	0.078	2.7	573
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