Fire Dynamics
Flame spread

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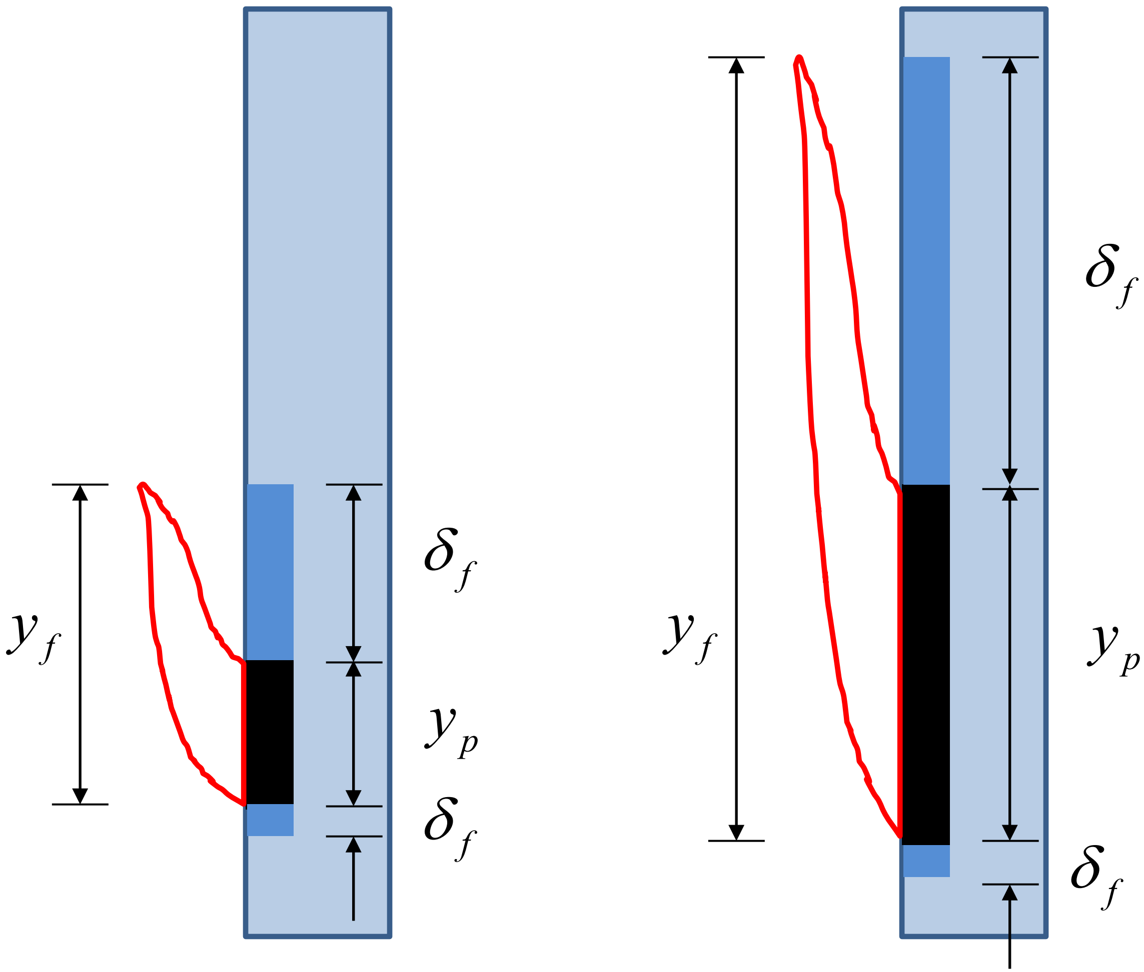
Objectives

- Understanding flame spread for
  - Solids
    - Concurrent flow flame spread
    - Opposed flow flame spread

Flame spread on solids

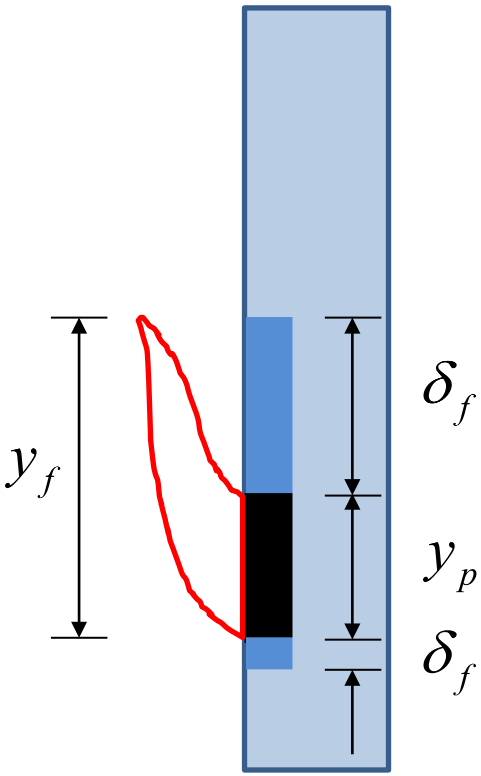


Concurrent flow flame spread

Opposed flow flame spread

Flame spread rate

- Flame spread rate(=pyrolysis front velocity) (v_p) ?



$$v_p = \frac{dy_p}{dt} = \frac{\delta_f}{t_f} = \frac{y_f - y_p}{t_f}$$

where,

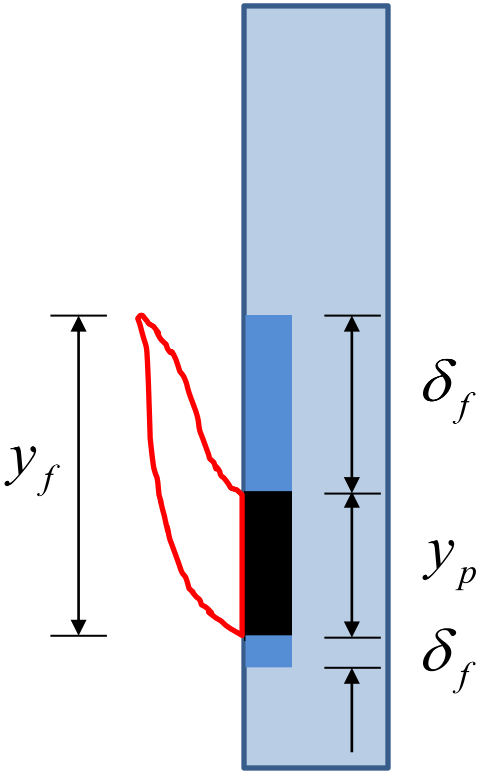
v_p = Flame spread rate [mm/s]

y_p = Pyrolysis height [mm]

y_f = Flame height [mm]

t_f = Ignition time of the region(δ_f)[s]

Flame spread rate



- For thermally thin

$$v_p = \frac{\delta_f}{t_f} = \frac{\delta_f}{\rho c_p d \left(\dfrac{T_{ig} - T_s}{\dot{q}_f''} \right)} = \frac{\dot{q}_f'' \delta_f}{\rho c_p d \left(T_{ig} - T_s \right)}$$

- For thermally thick

$$v_p = \frac{\delta_f}{t_f} = \frac{\delta_f}{\dfrac{\pi}{4} k \rho c_p \left(\dfrac{T_{ig} - T_s}{\dot{q}_f''} \right)^2} = \frac{4 \left(\dot{q}_f'' \right)^2 \delta_f}{\pi \left(k \rho c_p \right) \left(T_{ig} - T_s \right)^2}$$

Opposed flow flame spread rate

- Only for opposed flow and thermally thick
  - Lateral spread or downward spread
  - Flame spread rate ~constant

$$v_p = \frac{\delta_f}{t_f} = \frac{4\left(\dot{q}''_f\right)^2 \delta_f}{\pi\left(k\rho c_p\right)\left(T_{ig} - T_s\right)^2} = \frac{\Phi}{k\rho c_p\left(T_{ig} - T_s\right)^2}$$

where,

$$\Phi = \frac{4}{\pi}\left(\dot{q}''_f\right)^2 \delta_f \approx \text{ constant under natural convection}$$

i.e., $\dot{q}''_f$ and δ_f are linked together and material specific.

Opposed flow flame spread rate

- Typical range of flame spread

	T_{ig}(°C)	$k\rho c_p$[kW^{2}s/m^{4}K^2]	Φ [kW^2/m^3]	$T_{s',min}$	**v_p(mm/s)**
wood fiber board	355	0.46	2.3	210	**0.24**
wood hard board	365	0.88	11	40	**0.12**
plywood	390	0.54	13	120	**0.33**
pmma	380	1	14.4	90	**0.17**
flexible foam plastic	390	0.32	11.7	120	**0.5**
rigid foam plastic	435	0.03	4.1	215	**2.82**
acrylic carpet	300	0.42	9.9	165	**1.29**
wallpaper on plasterboard	412	0.57	0.8	240	**0.05**
glass-reinforced plastic	390	0.32	10	80	**0.33**

Flame spread rate

- Approximate ranges for variables

$$25 < \dot{q}''_f < 70 \quad [\mathrm{kW/m^2}]$$

$$\delta_f \approx 1 \sim 2 \quad [mm],\ \text{for opposed flow flame spread}$$

Example

Calculate the concurrent and opposed flame spread rates for plywood (thermally thick) 2 sec after the ignited region is 0.1 m high.

Assume the heat flux from the flame is 25 kW/m^2.

The lateral fire spread occurs after 120°C and the flame height is given as below.

$$y_f = 3y_p$$