Fire Dynamics
Burning rate

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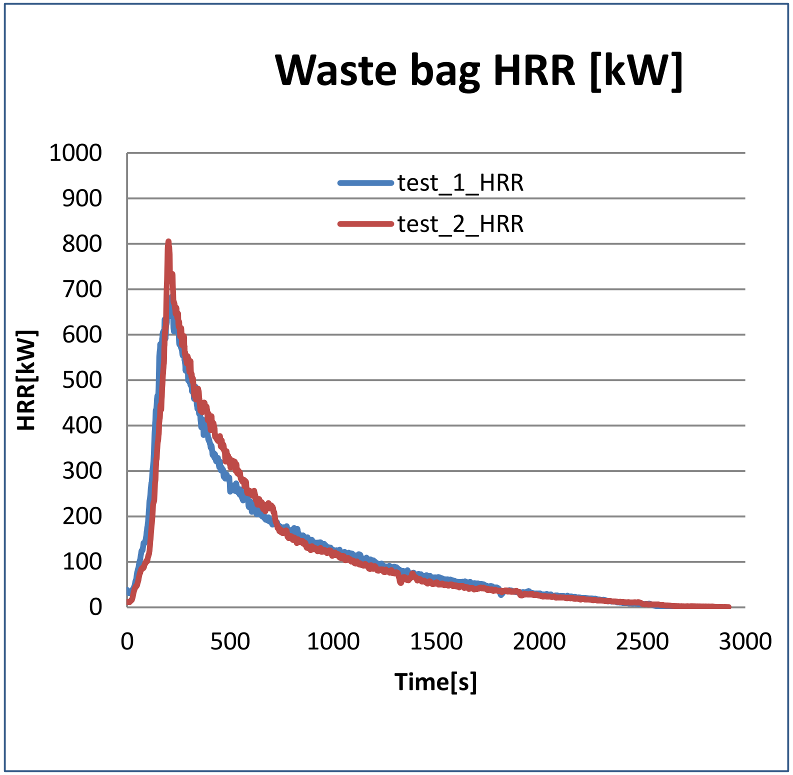
Objectives

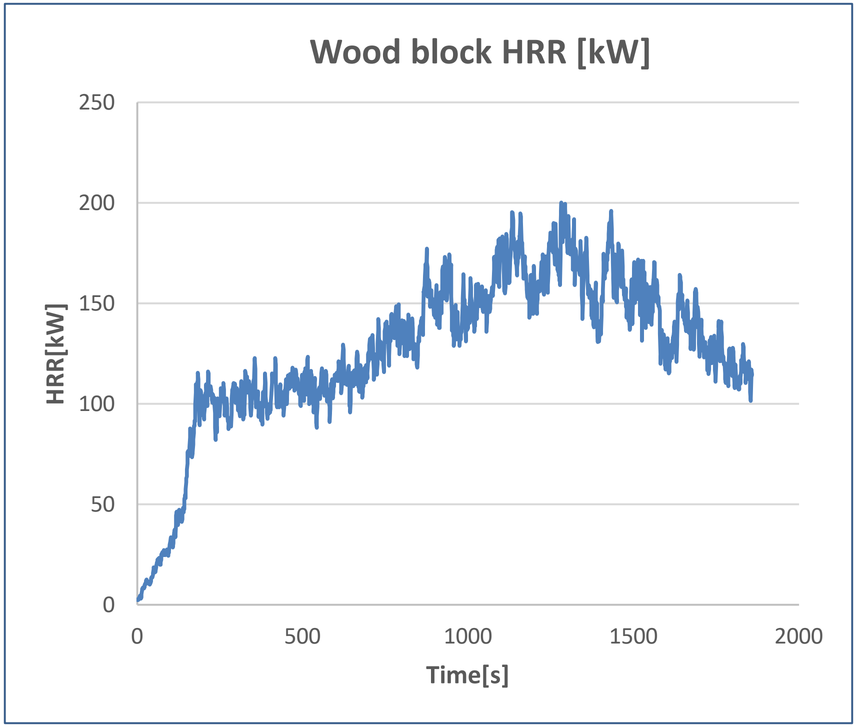
- Understanding burning rate
  - Heat release rate
  - Liquid burning
  - Solid burning

Heat release rate (HRR)



11.7 and 11.9 kg

Heat release rate (HRR)



22.5 kg

Heat release rate (HRR)

$$\dot{Q} = \dot{m}_a(\Delta H_{c,air}) = \dot{m}_a(3000 \text{ kJ/kg of air}), \text{ or}$$

$$= \dot{m}_f(\Delta H_{c,fuel})$$

where,

$\dot{m}_a$: air consumption rate [kg/s]

$\dot{m}_f$: fuel burning rate [kg/s]

$\Delta H_{c,fuel}$: heat of combustion of fuel [kJ/kg]

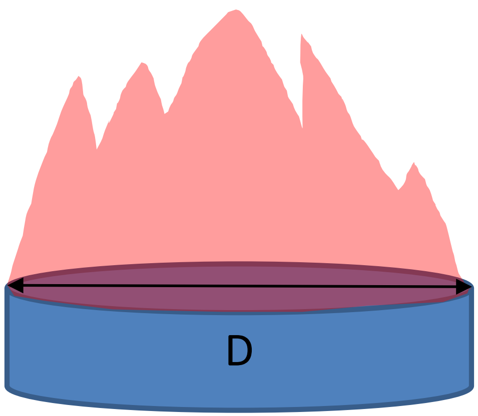
Heat release rate per unit area (HRR)

$$\dot{Q}'' = \frac{\dot{Q}}{A} = \frac{\dot{m}_f(\Delta H_c)}{A} = \dot{m}_f''(\Delta H_c)$$

where,

$\dot{m}_f''$: fuel mass burning rate per unit area[kg/m^2-s]

Pool(pan) fire burning rate



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

$\dot{m}''_\infty$ = reference fuel burning rate [kg/m^2-s]

k = extinction coefficient [1/m]

β = mean beam length corrector

D = fuel diameter [m]

When $D \to \infty$, $\dot{m}''_f = \dot{m}''_\infty$

$$\dot{q}''[\mathrm{kW/m^2}] = \dot{m}''_f (\Delta H_c) = \dot{m}''_\infty (1 - \mathrm{e}^{-k\beta D})(\Delta H_c)$$

$$\boxed{\begin{aligned}\dot{q}[\mathrm{kW}] &= \dot{m}''_f A_s (\Delta H_c) = \dot{m}''_\infty (1 - \mathrm{e}^{-k\beta D}) A_s (\Delta H_c) \\ &= \dot{m}''_\infty (1 - \mathrm{e}^{-k\beta D}) \left(\frac{\pi}{4} D^2\right) (\Delta H_c)\end{aligned}}$$

Liquid burning rate

- Pool fire burning rate data

If $\dot{m}''_\infty$ is unknown,

$$\dot{m}''_\infty \approx \frac{\Delta H_c}{\Delta H_{vap} + c_p (T_b - T_{init})}$$

	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
Acetone	25.8	0.041	1.9	791
Gasoline	43.7	0.055	2.1	740
Kerosene	43.2	0.039	3.5	820

Liquid burning rate

If $\dot{m}''_{\infty}$ is unknown, using the following emprical correlation,

$$\dot{m}''_{\infty} \approx \frac{\Delta H_c}{\Delta H_{vap} + c_p (T_b - T_{init})} \text{ [g/m}^2\text{-s]}$$

where,

ΔH_c = heat of combustion [kJ/g]

$\Delta H_{vap} = L_v$ = heat of vaporization [kJ/g]

c_p = specific heat of liquid fuel [kJ/kg-K]

T_b = boiling temperature [K or $^{\circ}$C]

T_{init} = initial temperature [K or $^{\circ}$C]

Solid burning rate

- Solid material burning rate data

	Heat of gasification [kJ/g]
Polystyrene foams	1.31 to 1.94
Polyurethane foams	1.19 to 2.7
Nylon 6/6	2.35 to 3.8
Corrugated paper	2.21
Douglas fir	1.82
Woods	4 to 6.5

$$\dot{m}'' \approx \frac{\dot{q}''_{net}}{L}$$

$$\dot{q}''_{net} = \text{Net heat flux to fuel surface [kW/m}^2\text{]}$$

$$L = \text{Effective heat of gasification [kJ/g]}$$

Example

Calculate the heat release rate of heptane
in a 0.3 m by 0.3 m pan and the amount (L)
of heptane to burn for 10 min.
What would be the minimum height of the pan?