SP Technical Research Institute of Sweden

Latest advance of research on tunnel fire dynamics

Ying Zhen, Li

SP Technical Research Institute of Sweden

Email: yingzhen.li@sp.se

SP Tunnel and Underground Safety Centre

Content

1. **Design fire** (Fire size, Fire Growth rate)
2. **Flame length**
3. **Maximum ceiling gas temperature**
4. **Ceiling temperature distribution along tunnel**
5. **Smoke control**

   (Longitudinal, point extraction, cross-passage)

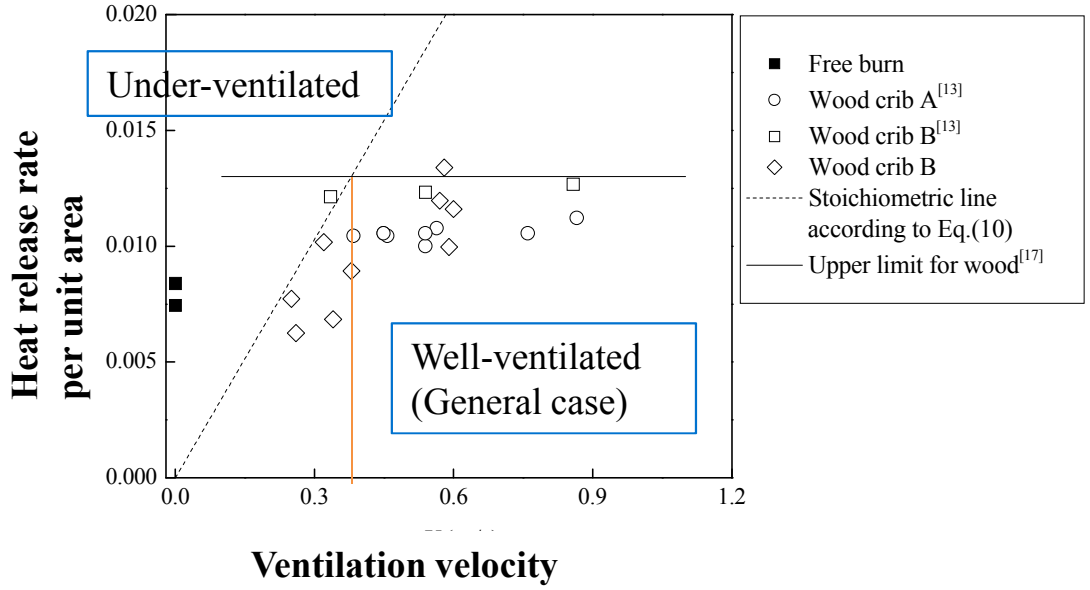
Note: For fire in enclosed vehicles, the fire could be ventilation controlled.

1. Design fire

Fire size (HRRmax)

For solid fuels exposed to wind and well ventilated fires: $Q = \dot{m}''_f A_f \Delta H_{c,eff}$

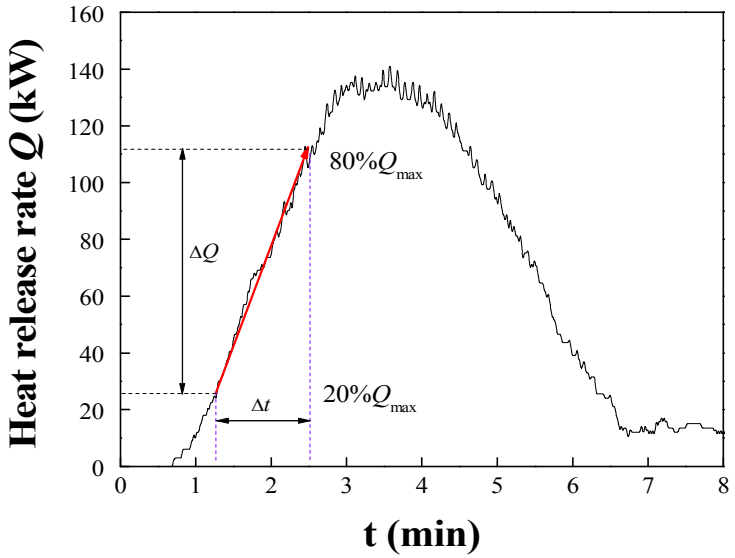
- **Limited effect** of ventilation
- **Limited effect** of tunnel walls

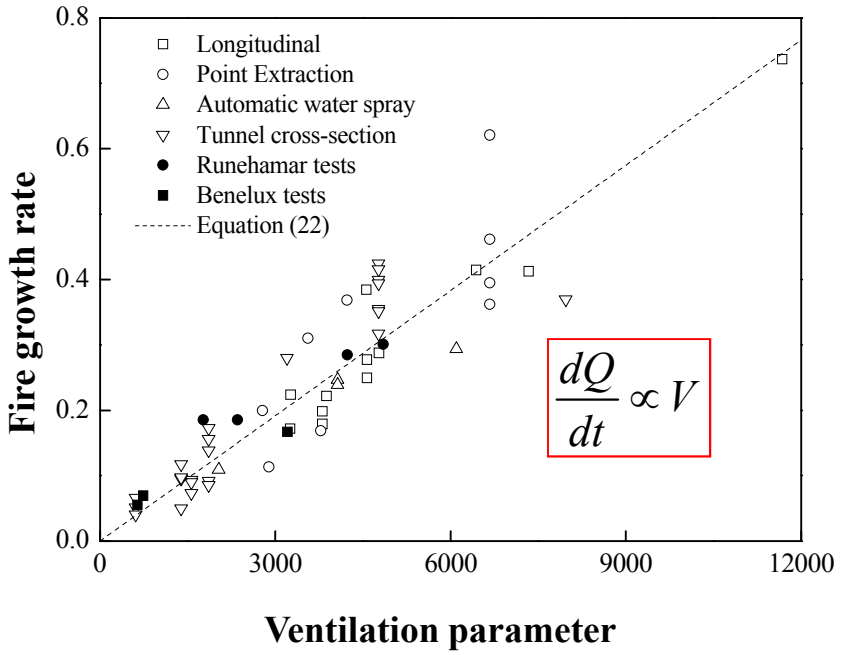


Note: For fire in enclosed vehicles, the fire could be ventilation controlled.

Fire Growth rate (FGR)

For solid fuels exposed to wind:
Longitudinal spread dominates.





Fire growth rate:

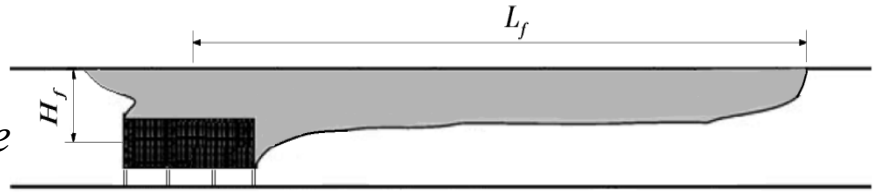
$$\frac{dQ}{dt} = \frac{\Delta Q}{\Delta t}$$

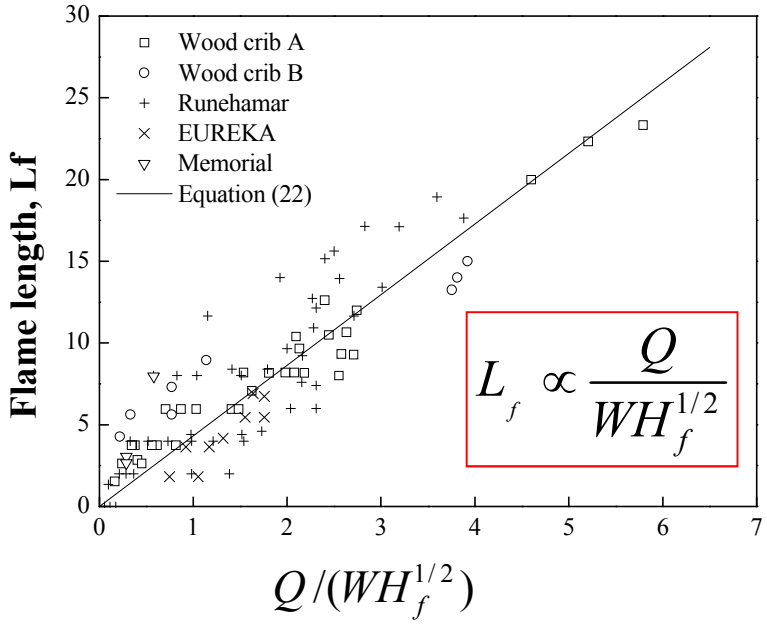
Fire growth rate **increases linearly** with ventilation velocity.

Note: For fire in enclosed vehicle, the ventilation could have **limited effect**.

2. Flame length

Definition: *horizontal distance between flame tip and fire centre*



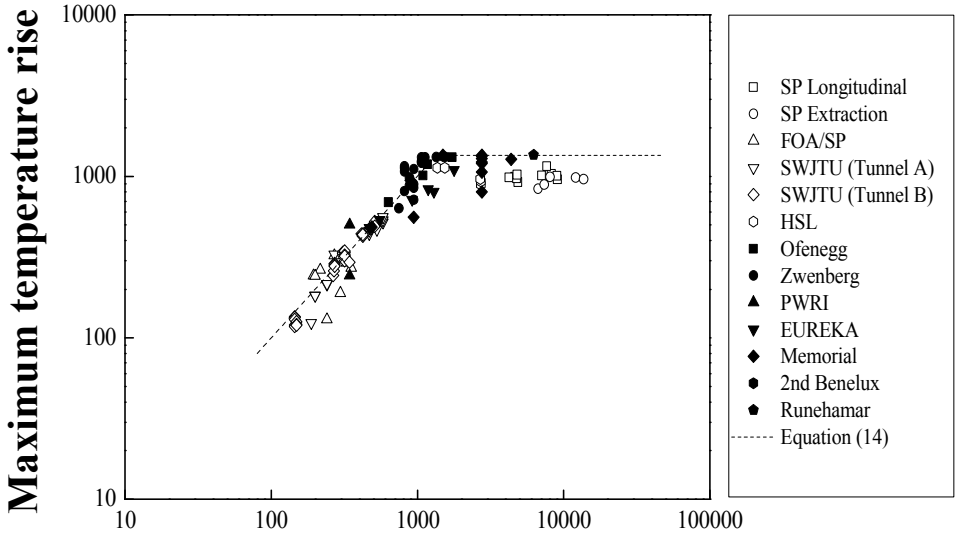


Flame length, *Lf*

- *increase linearly with HRR*
- *decrease with tunnel width*
- *not sensitive to ventilation*

3. Maximum ceiling gas temperature

Low ventilation (Region I) → General case for natural and transverse ventilation



$$\mathrm{DTR}\,1 = 17.5\frac{Q^{2/3}}{H_{ef}^{5/3}}$$

Region I:

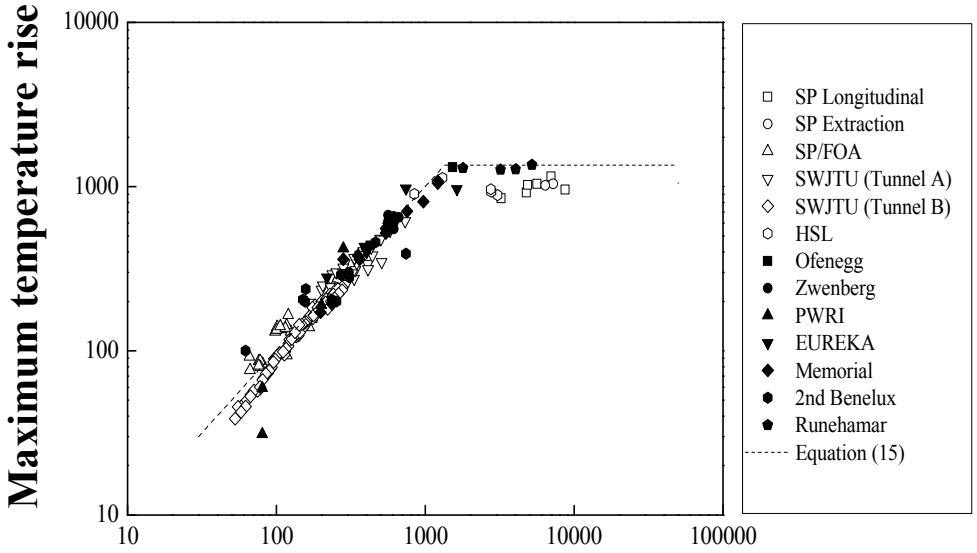
$$V' = V\,/\left(\frac{gQ}{b_{fo}\rho_o c_p T_o}\right)^{1/3} \le 0.19$$

Below 1350 °C, maximum excess gas temperature at low ventilation varies as:

- 2/3 power of Q
- -5/3 power of *Hef*
- insensitive to velocity

High ventilation (Region II) →

General case for Longitudinal ventilation



Region II: $V' > 0.19$

$$\text{DTR } 2 = \frac{Q}{VH_{ef}^{5/3} b_{fo}^{1/3}}$$

Below 1350 °C, maximum excess gas temperature:

- proportional to Q
- inversely proportional to velocity, V
- -5/3 power of H_{ef}
- -1/3 power of fire radius, b_{fo}.

Example of use

- HGV fire and Hydrocarbon time-temperature curve (HC)

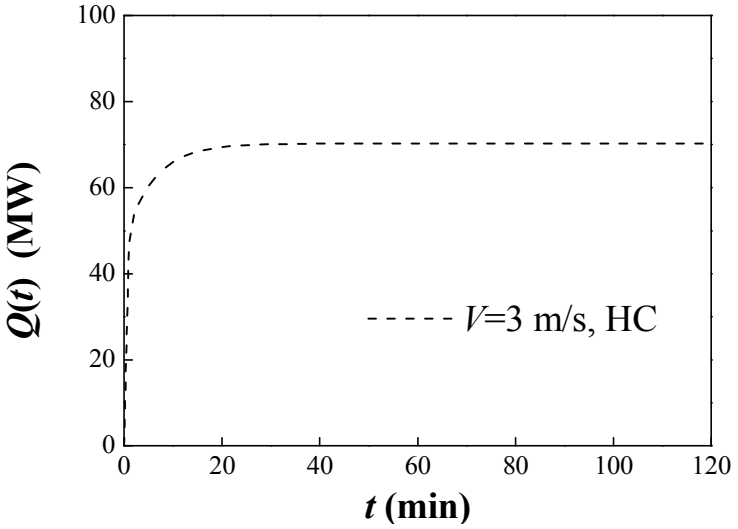
- Tunnel height: 6 m / Tunnel width:12 m

- The effective tunnel height from the bottom of the fire load up to the ceiling, H_{ef}, is 4.8 m.

- The radius of the fuel, b_{fo}, is 4 m.

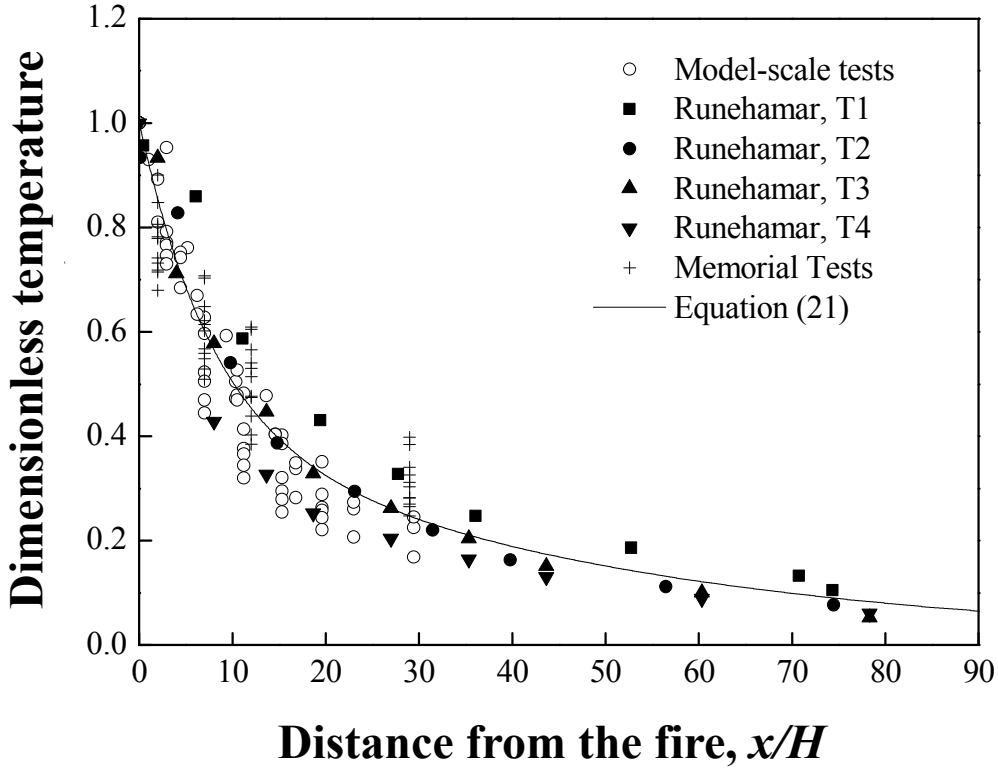
- The longitudinal velocity, V, is assumed to be 3 m/s.

- The ambient temperature is 10 °C.



4. Ceiling temperature along tunnel

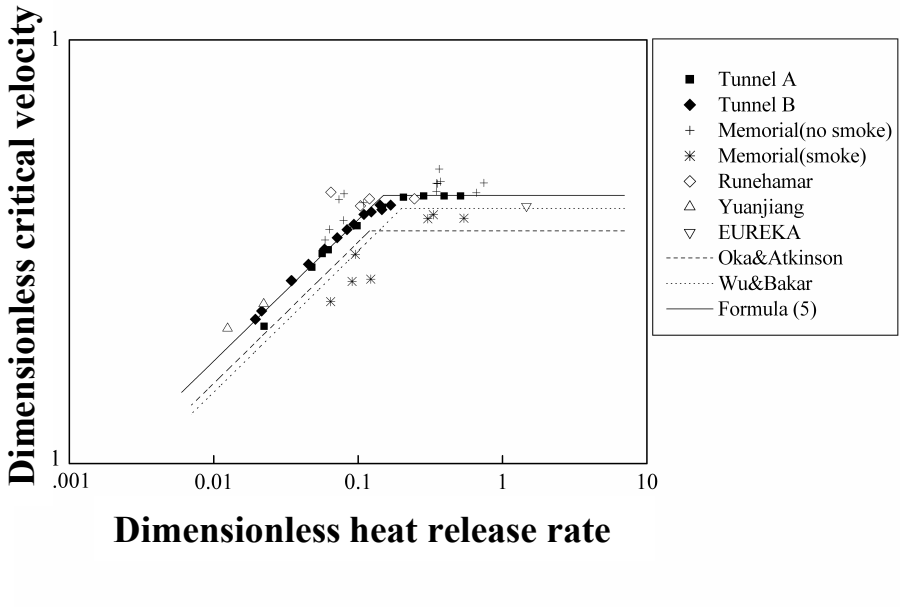
Dimensionless distance: x_f/H

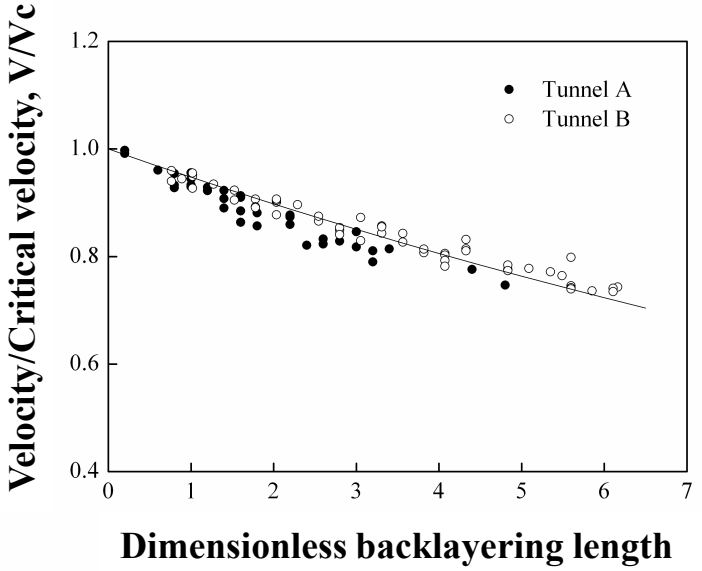


It shows how the temperature decreases with distance from the fire.

5. Smoke control

Longitudinal ventilation

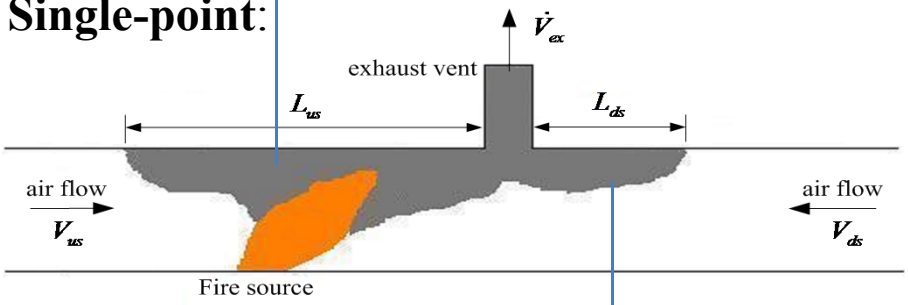




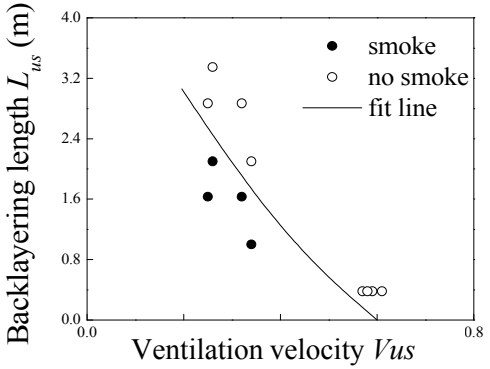
Point extraction

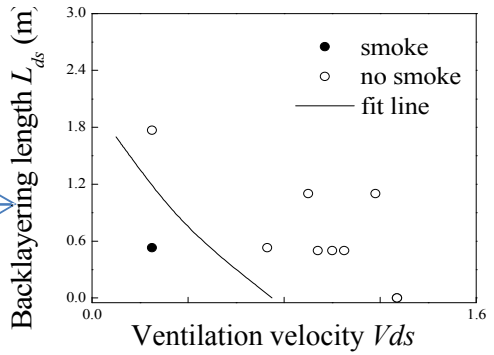
upstream

Single-point:

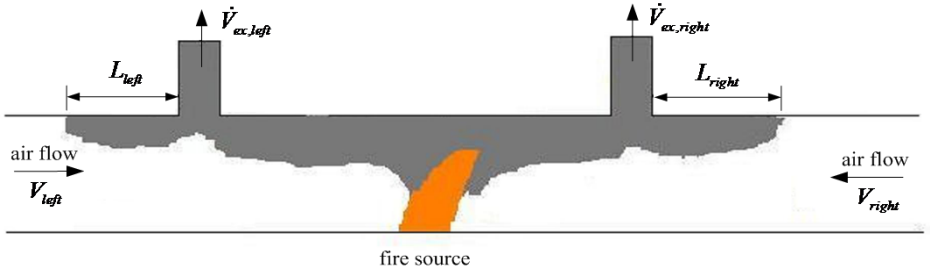


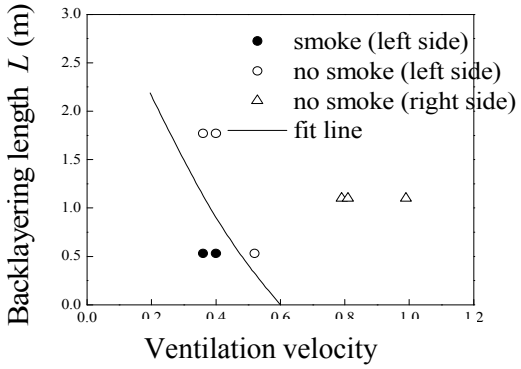
downstream





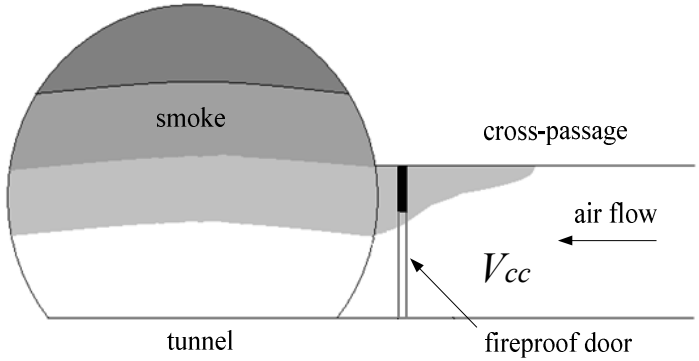
Two-point:

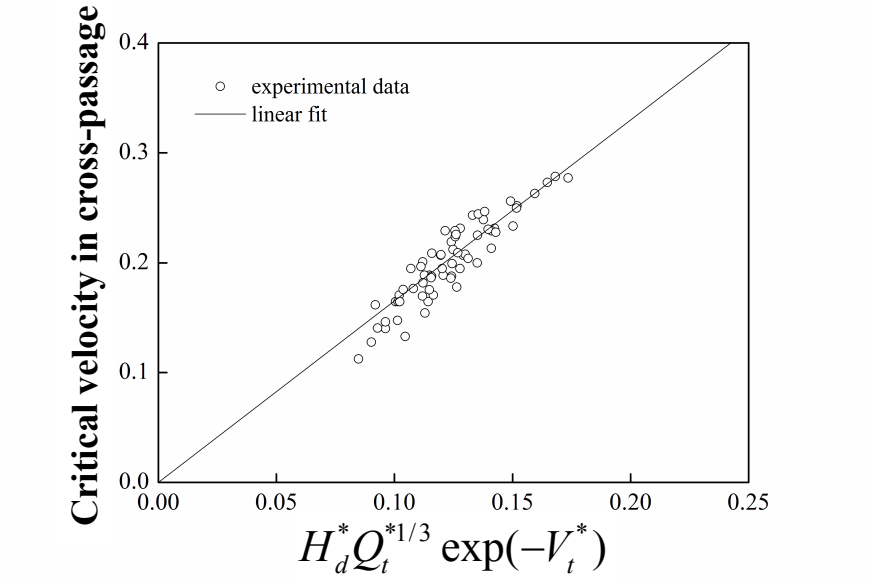




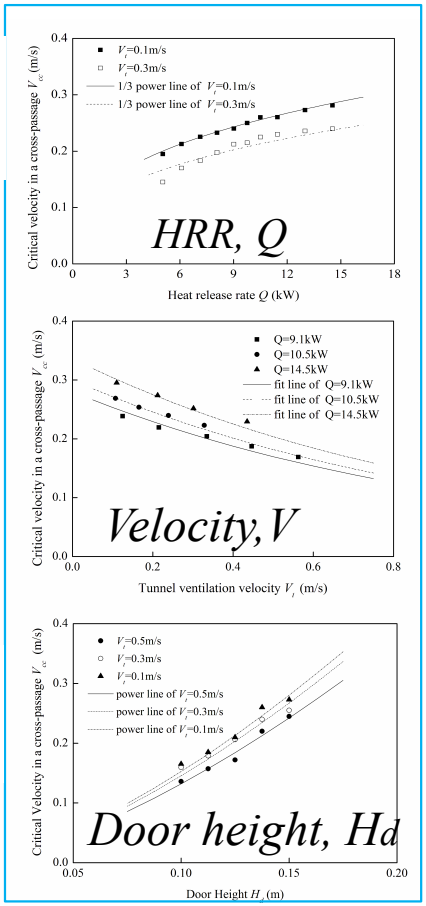
Critical velocity from both sides.

Cross-passage and Rescue station





Vcc



Conclusion

- **Design fire**: HRR, FGR
- **Flame length**: Q, W
- **Maximum ceiling temperature**: Q, V, H_{ef}, b_{fo}
- **Ceiling temperature distribution**: x/H
- **Smoke control**
  - → *Longitudinal ventilation*: V_c, L_b
  - → *Point extraction*: Critical velocity from both sides
  - → *Cross-passage/Rescue station*: V_{cc}

Thanks for your attention!

Ying Zhen Li

SP Technical Research Institute of Sweden

Email: yingzhen.li@sp.se