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Initial Assessment of the Impact of Jet Flame Hazard From Hydrogen Cars In Road Tunnels

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Hydrogen Economy and Hydrogen Fuelled Vehicles

Hydrogen as fuel will be first introduced into the transportation systems.

Markets for hydrogen fuel already exist in road transport through a number of demonstration projects.

Global energy companies are tackling the infrastructure requirements for a substantial hydrogen production and distribution system.

The hydrogen economy is predicted to arrive in 15 to 20 years.

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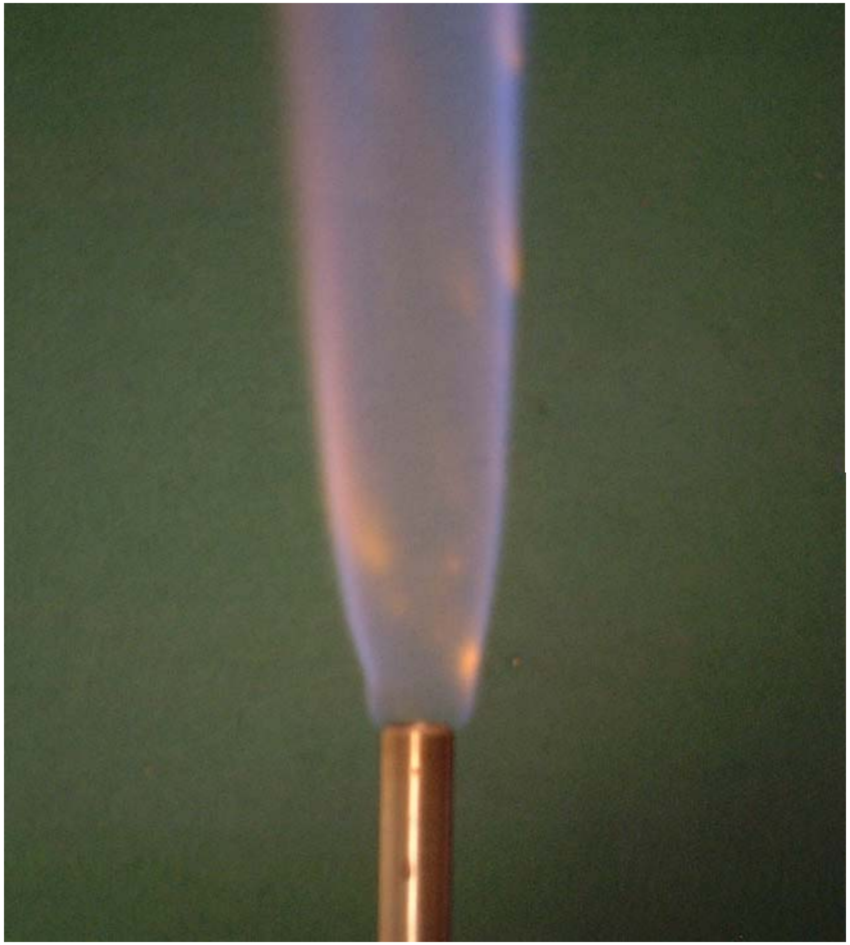
Future Road Tunnel Users

When hydrogen economy takes off, hydrogen cars would be regular users of urban transportation systems.

The use of underground space became more and more important all over the world. The volume of tunnelling construction is expected to be around 2,100 km in Europe and 2,350 km in Asian in next 10 to 15 years.

The sustainability of tunnelling activities requires consideration of impacts of hydrogen cars as the future users of the existing tunnels and new tunnels to be constructed

Characteristic Properties of Hydrogen Fuel



Flame Temperature:
2318 K

Auto ignition temperature:
858 K

Heat of combustion :
119.93 kJ/g

Radiation Energy to surroundings:
17 to 25%

Burning Velocity:
265 to 325 cm/s

Minimum Ignition Energy
0.017 mJ

Hydrogen Jet Flames

In day light

In dark

Hazard Posed by Hydrogen Release from High Pressure Source

Subsonic and supersonic jet release.

Ignitibility: Very low ignition energy

Minimum Ignition Energy

hydrogen (0.017 mJ)

methane (0.29 mJ)

gasoline (0.24 mJ)

Stability: Once ignited, hydrogen jets produce very stable diffusion jet flames.

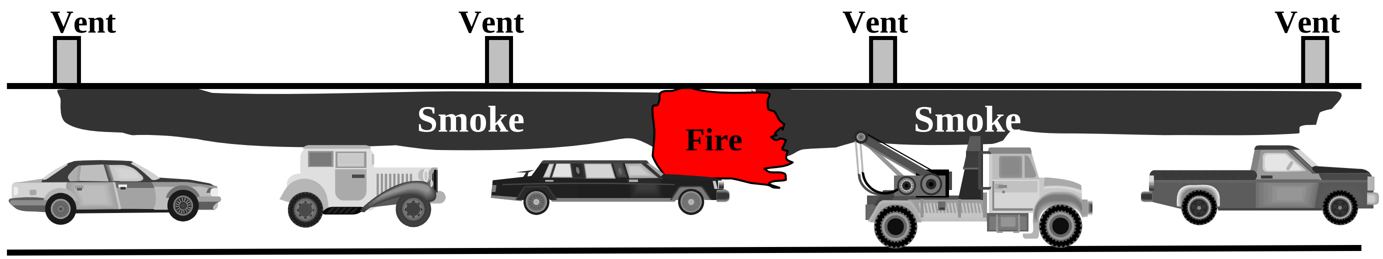
Jet flame is a dominating feature companying hydrogen fuel release

Objectives

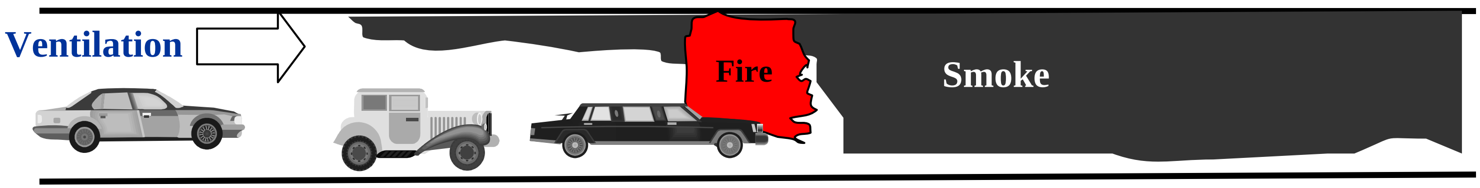
Carry out initial assessment of the fire hazards and worst jet fire scenarios associated with hydrogen fuel release inside tunnel.

CFD simulations to assess the implication hydrogen fire on the tunnel ventilation systems.

Tunnel Ventilation Systems



A tunnel fire and smoke flow under influence of transverse ventilation



A tunnel fire and smoke flow under influence of longitudinal ventilation

Smoke Flow Under Influence of Tunnel Ventilation

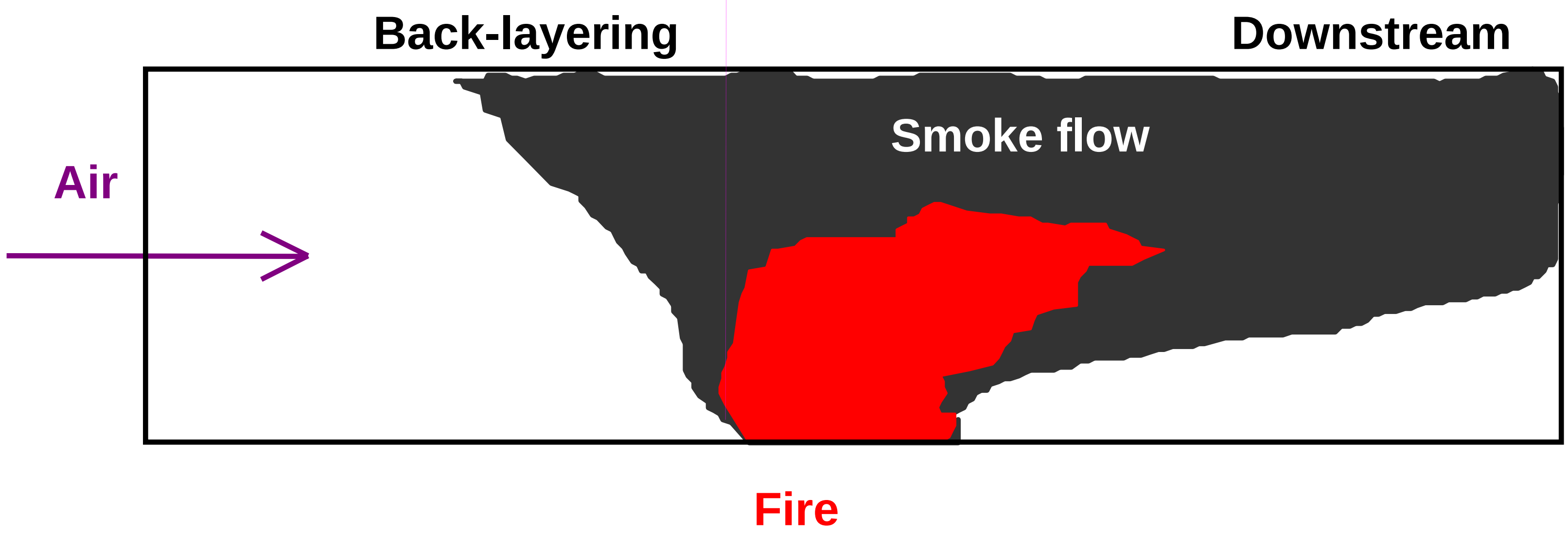
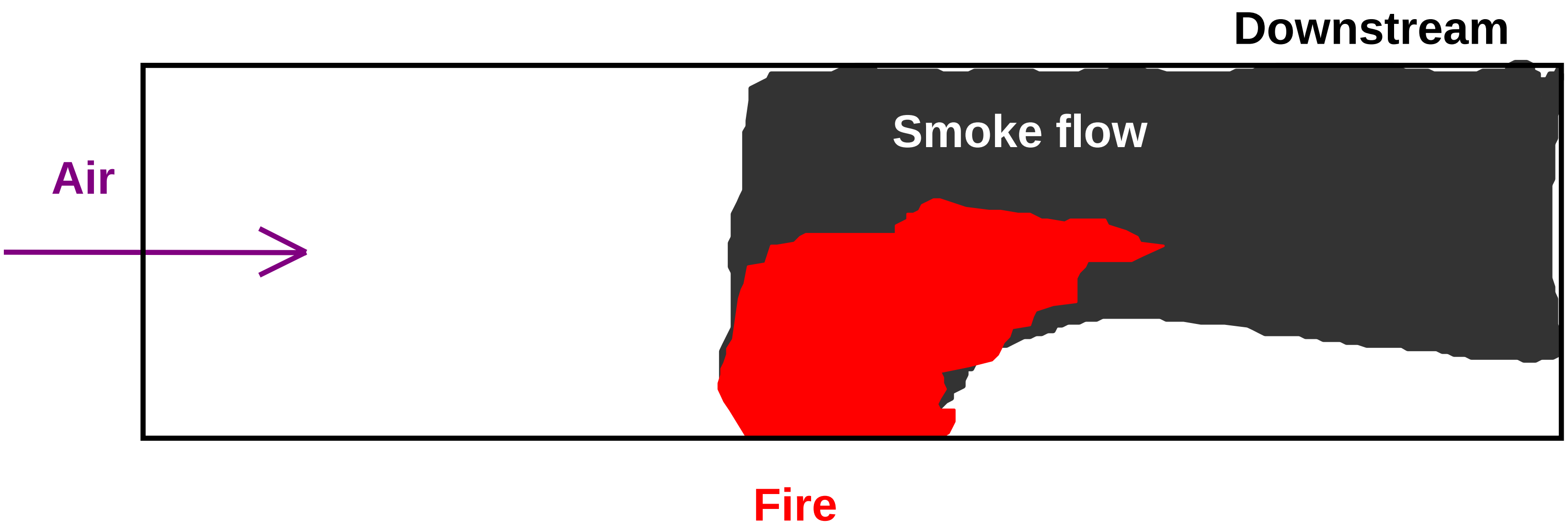


Illustration of the blacklayering, fire plume and downstream smoke flow

Smoke Flow Under Critical Ventilation Condition

Critical Ventilation Rate



The "critical velocity" is defined as the minimum air velocity required to suppress the smoke flow spreading against the longitudinal ventilation flow during tunnel fire situations.

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Hydrogen Car Fire

Currently hydrogen stored on board on a fuel cell vehicle is mainly in high pressure compressed gas form.

The storage pressure:

20, 35 or 45 MPa

Storage capacity:

approximate 3 to 5 kg at present.

Almost all accidents occurred were associated with hydrogen release.

Selected scenarios for the assessment:

Ignited hydrogen jet release in the tunnel.

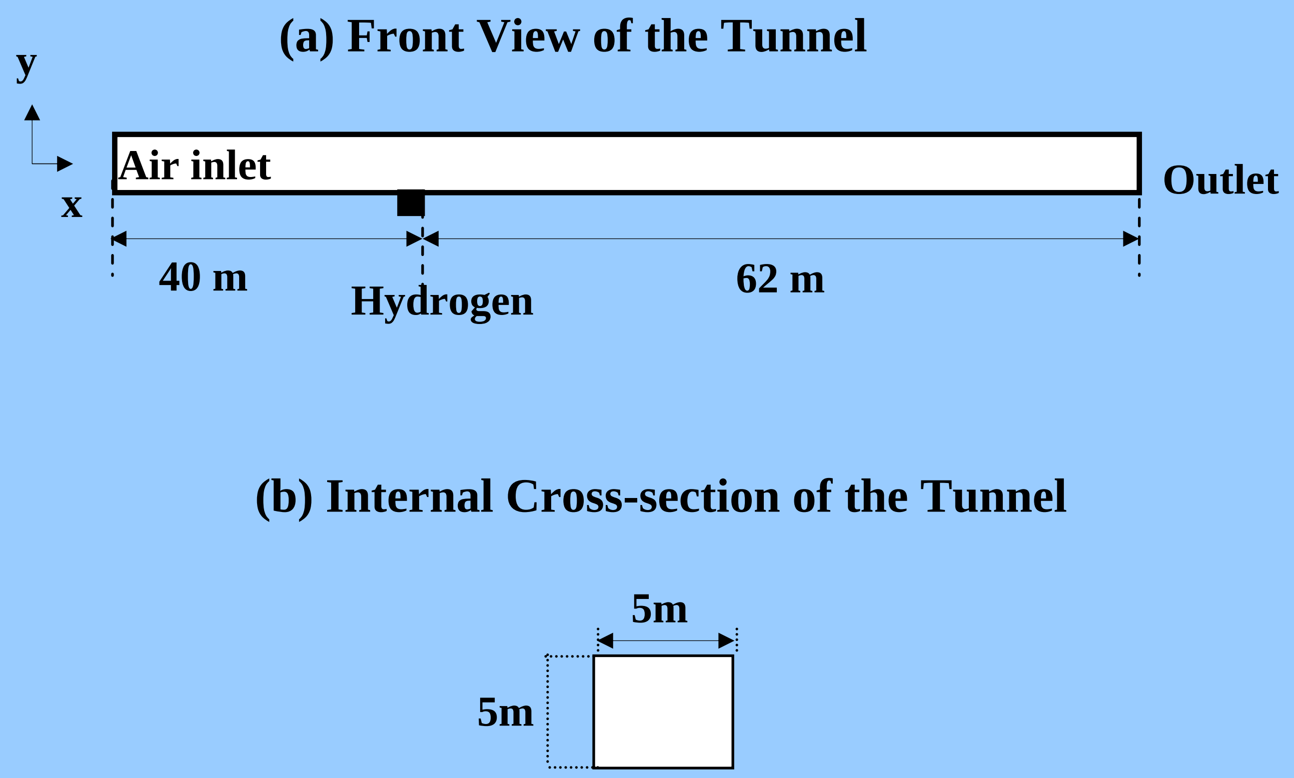
6MW Fire:

Hydrogen is released at rate of 0.05 kg/s and at velocity 10 m/s in 1 minute duration.

30MW Fire:

Released at rate of 0.25 kg/s and velocity of 50 m/s with a shorter duration.

CFD Simulations of Hydrogen Car Fires inside Tunnels under Longitudinal Ventilation



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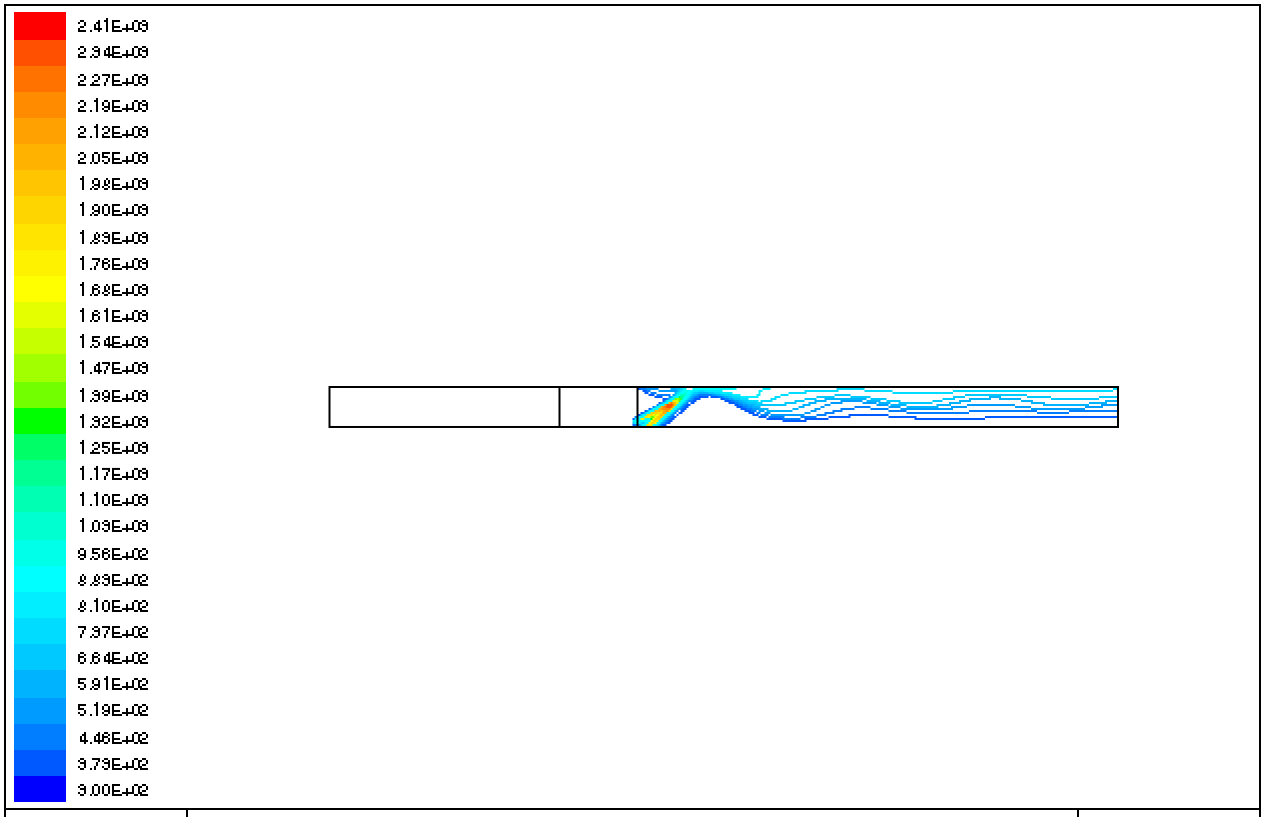
Critical Velocity

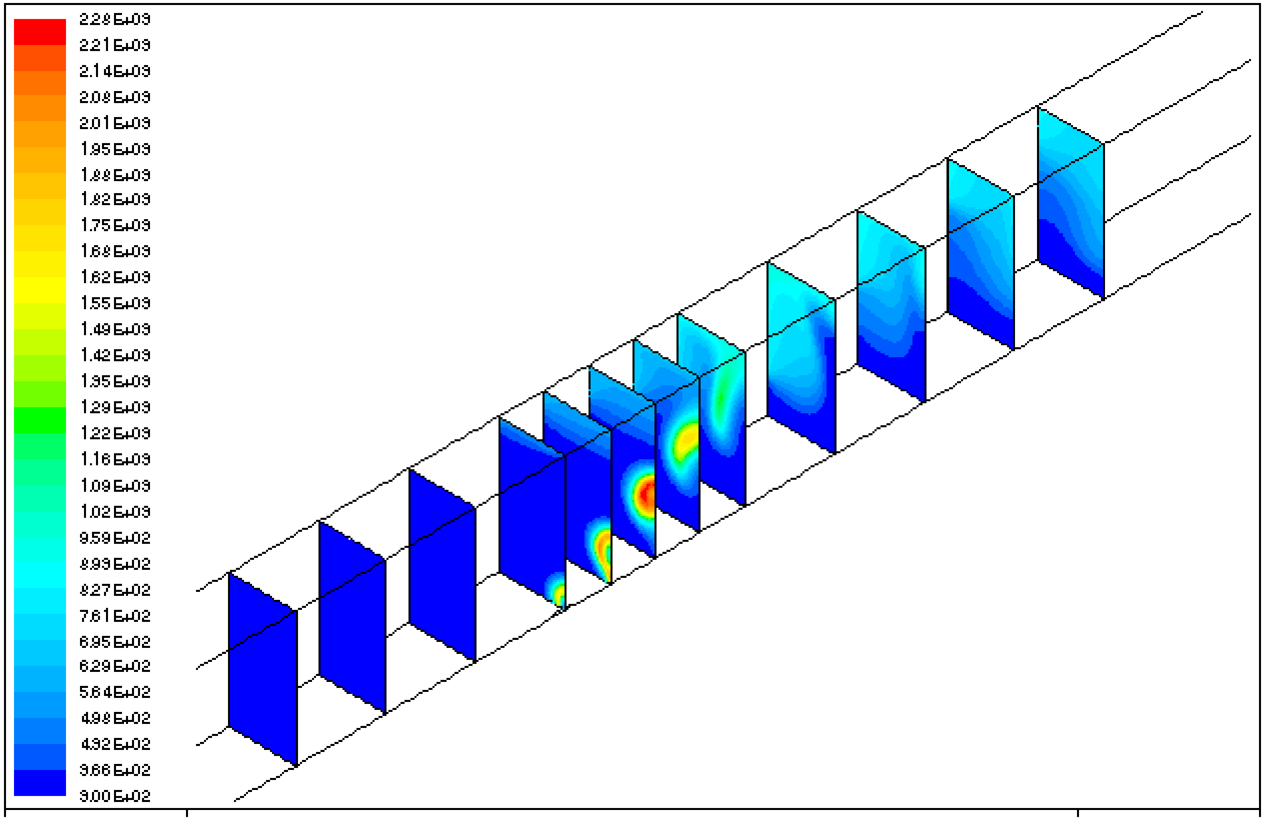
For the 5m by 5m square cross-section tunnel, our previous studies gave the value of super-critical ventilation velocity as 2.5 m/s, which would eliminate the back layering and force the smoke moving downstream only regardless what the magnitude of the heat output from the fire is.

The critical velocity is tested for the 6MW and 30MW hydrogen fires.

6 MW Hydrogen Fire and 2.5 m/s Ventilation. Temperature Contours on the Tunnel Symmetrical plane

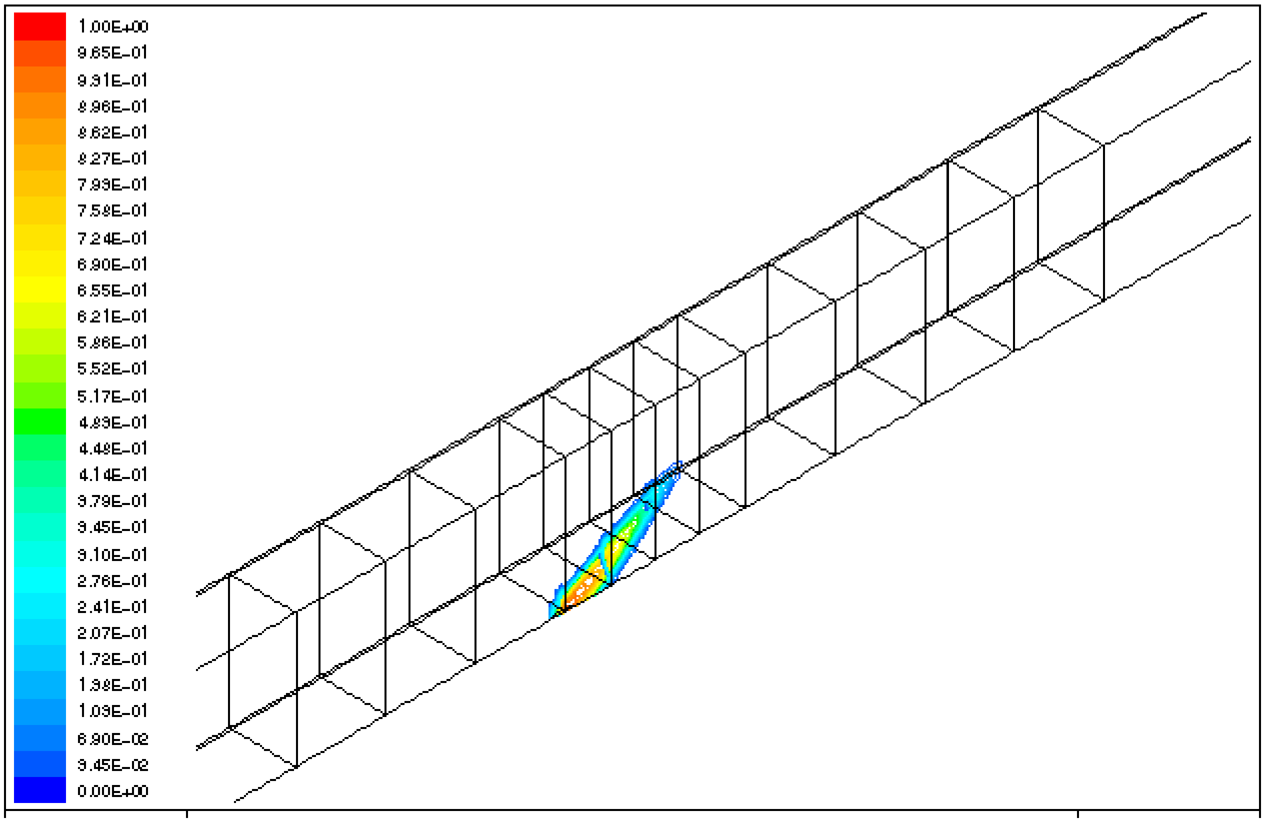


6 MW Hydrogen Fire and 2.5 m/s Ventilation Temperature contours on tunnel cross-sections

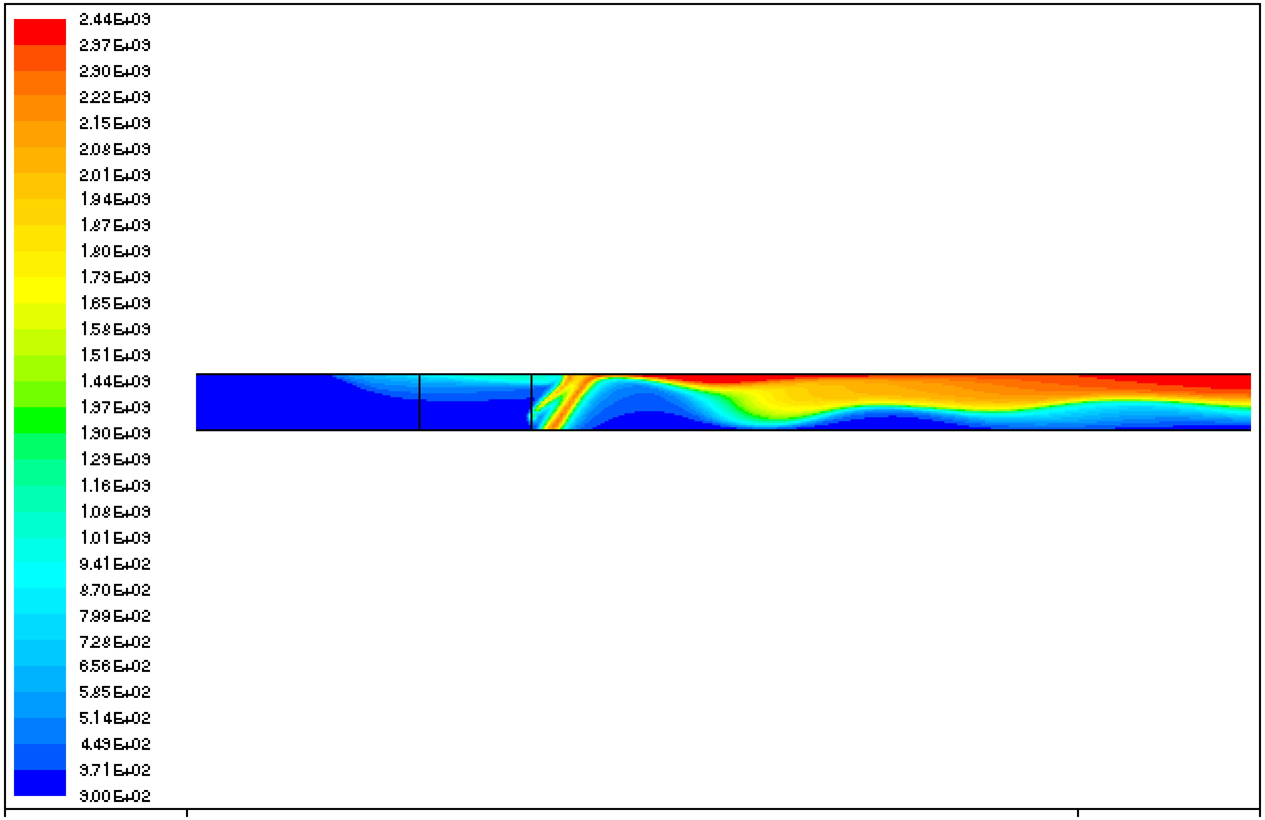


6 MW Hydrogen Fire and 2.5 m/s Ventilation

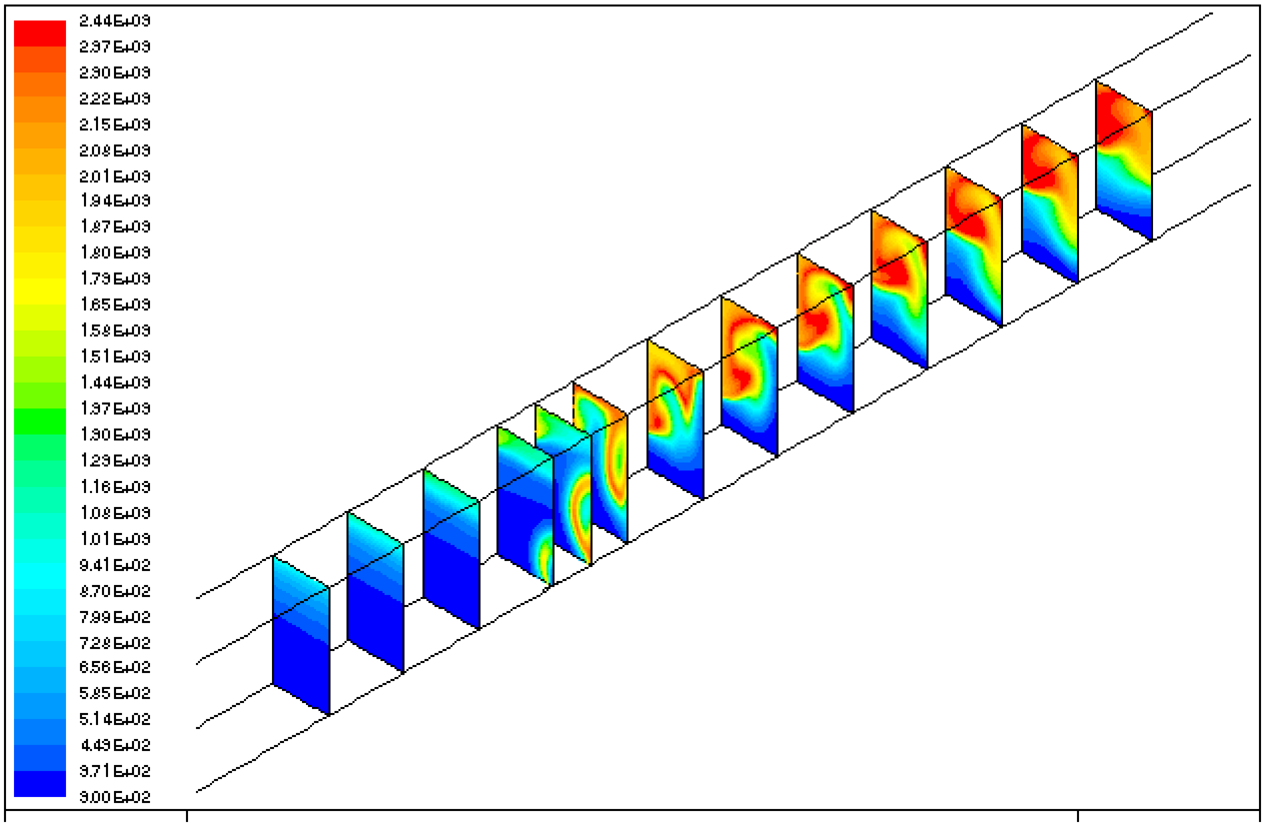
Hydrogen mole fraction contours on the symmetrical plane



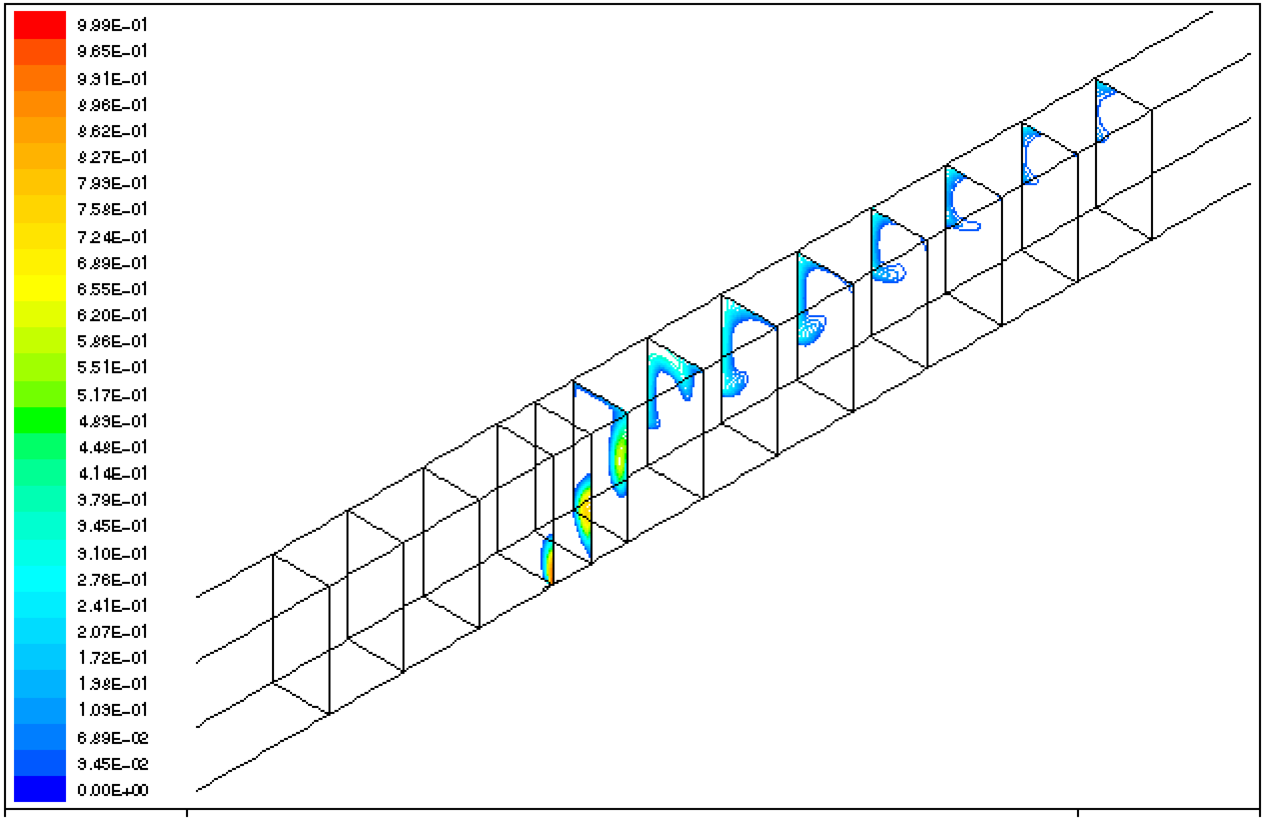
30 MW Hydrogen Fire and 2.5 m/s Ventilation. Temperature contours on the tunnel symmetrical plane

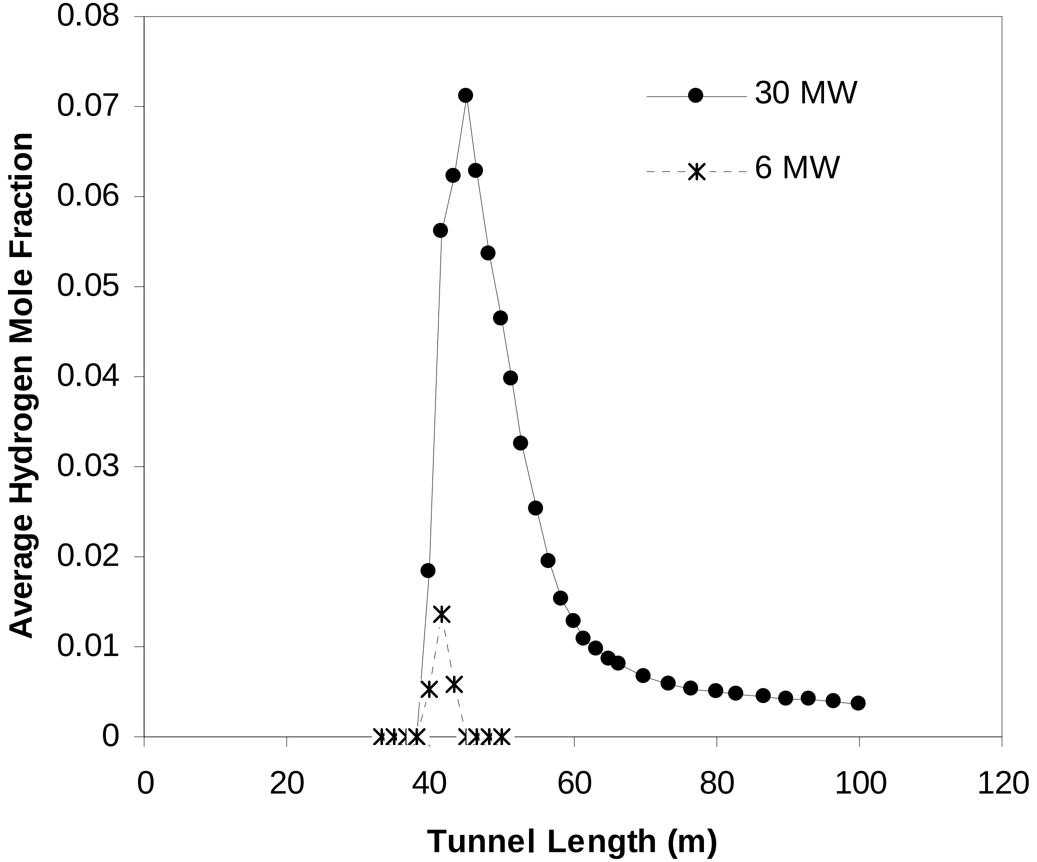


30 MW Hydrogen Fire and 2.5 m/s Ventilation
Temperature contours on tunnel cross-sections



30 MW Hydrogen Fire and 2.5 m/s Ventilation
Hydrogen mole fraction contours on the symmetrical plane





THE AVERAGE MOLE FRACTION DISTRIBUTION INSIDE THE TUNNEL

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Critical Velocity

6MW Fire:

The ventilation (2.5 m/s) has fully eliminate the backlayering.

30 MW fire:

The ventilation flow didn’t eliminate the backlayering, however the length of the backlayering was controlled within the length of three tunnel heights.

Jet Flame Hazards

6MW fire:

Flame length was short and located in lower part of tunnel.

30MW fire:

Flame reached the tunnel ceiling and spread under ceiling for a long distance (45 m) downstream.

Oxygen Deficiency

6MW fire:

There was no oxygen deficiency and the flame length was short and within two tunnel heights downstream.

30MW fire:

The oxygen deficiency caused the hydrogen spread downstream under the ceiling for a long distance and the reacting flow produced high temperature under the ceiling.

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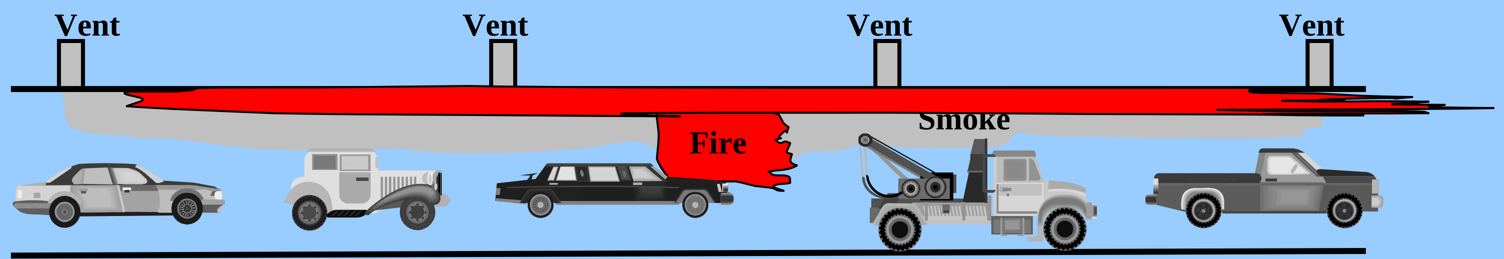
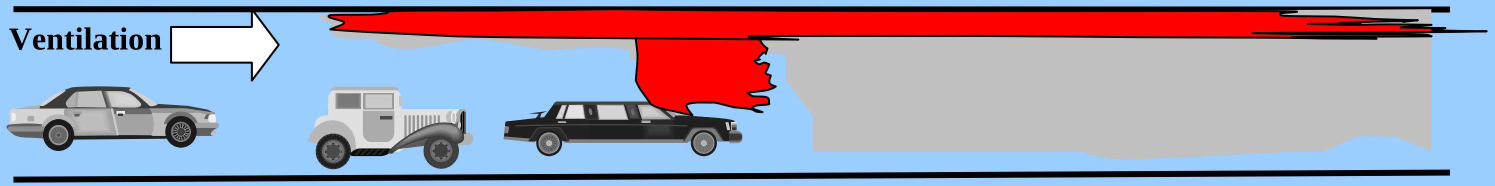
Oxygen Deficit Hydrogen Layer under Tunnel Ceiling



Under influence of transverse ventilation



Under influence of longitudinal ventilation

Conclusions

The super-critical ventilation velocity can completely eliminate the backlayering in normal hydrogen release rate or keep the backlayering under control in very high release rate.

Jet flame hazard could be the dominant feature for hydrogen cars inside tunnel.

For high release rate, the flame inside the tunnel might be in the status of oxygen deficit. This would result impingement of hydrogen jet flame on the tunnel ceiling and produce high temperature ceiling flow reaching substantial distance and damage tunnel infrastructures.

The oxygen deficit hydrogen fire also pose flashover hazard inside tunnel and ventilation ducts.

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Thank you !