Innovative firefighting and ventilation in tunnels

The combination of low-pressure mist systems and jet fans with shaped silencers delivers dramatic improvements in cost and sustainability, while tackling the requirements for firefighting and ventilation in tunnels. This article reports on recent research and the latest installations in tunnels worldwide.

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The risk of fires in vehicular tunnels, whilst small, is unfortunately ever-present. The consequences of fires in enclosed spaces such as tunnels can be catastrophic, due to the generation of toxic smoke and the restricted means of escape available. A timely reminder of these risks was the car fire in the northbound Blackwall Tunnel in London on 9 April 2021, which necessitated the evacuation of around 100 motorists but which fortunately did not lead to any casualties. Other tunnel fires have had fatal consequences – for example, the Mont Blanc tunnel fire between France and Italy on 24 March 1999 caused 39 fatalities. The fire originated in a heavy goods vehicle carrying margarine, which is thought to have suffered a mechanical failure. Thirty-six vehicles were destroyed, and the fire burned for 53 hours and reached temperatures of 1,000°C. The tunnel structure was damaged over a distance of 900m.

▼ Smoke billowing out from the Blackwall Tunnel.

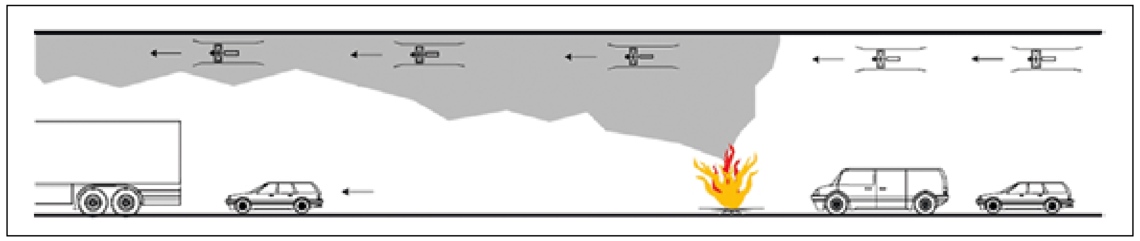
Two of the primary mitigation measures available to address the risk of fires in tunnels are ventilation (to clear smoke and allow pedestrians to escape to safety) and fire suppression (to reduce the fire size and to prevent it from spreading). Both of these measures have been the subject of intensive research to improve their effectiveness, while reducing their cost and environmental footprint.

One of the most popular means of smoke ventilation in tunnels is by using jet fans, particularly for unidirectional traffic. In case a fire breaks out, jet fans act to generate a longitudinal thrust to push the smoke in the downstream direction. Vehicles in front of the fire can drive out of the tunnel, while those trapped behind the fire are protected from smoke.

While jet fans are very useful tools for smoke control, they are quite inefficient, typically losing between 25 to 75% of their thrust compared to the thrust value measured on a bench in a factory. The two primary reasons for their inefficiency are the aerodynamic friction between the discharged jet and the tunnel surfaces (soffit and walls), and the unloading of downstream jet fans due to the ingestion of high-speed air issued by upstream jet fans. Designers compensate for these factors by specifying more jet fans, but the net result is that the design solution with conventional jet fans requires more fans, more cabling and a significantly higher operational cost compared to what the jet fan bench thrust would imply.

In order to address these issues, engineers at MoJet Ventilation have developed a new type of jet fan with shaped silencers, to deflect the airflow away from the bounding tunnel surface. This enhances the mass flow through the fan, and reduces both the aerodynamic friction and the unloading effect. Their patented solution, the MoJet, was developed using 3D Computational Fluid Dynamics (CFD), and has now been successfully tested in two tunnels: the Montgomery tunnel in Brussels, Belgium and the Mersey Queensway tunnel in Birkenhead, England. The results show an increase in thrust of between 30% and 100% for the MoJet compared to conventional jet fans, depending on the shape of the tunnel and the location of the MoJets. Conversely, the results show that power consumption reductions of up to 50% can be obtained by using MoJets, while delivering the required velocities for smoke control. With mechanical ventilation typically absorbing several megawatts in tunnels, such reductions imply impressive reductions in capital and operating costs, and significant improvements in tunnel sustainability.

Although smoke ventilation is a standard requirement for tunnels, another fire-risk mitigation measure is now becoming more prominent in tunnels worldwide, namely fixed fire-suppression systems. This involves discharging a fire suppressant – usually clean water – into the zone where a fire has been detected.



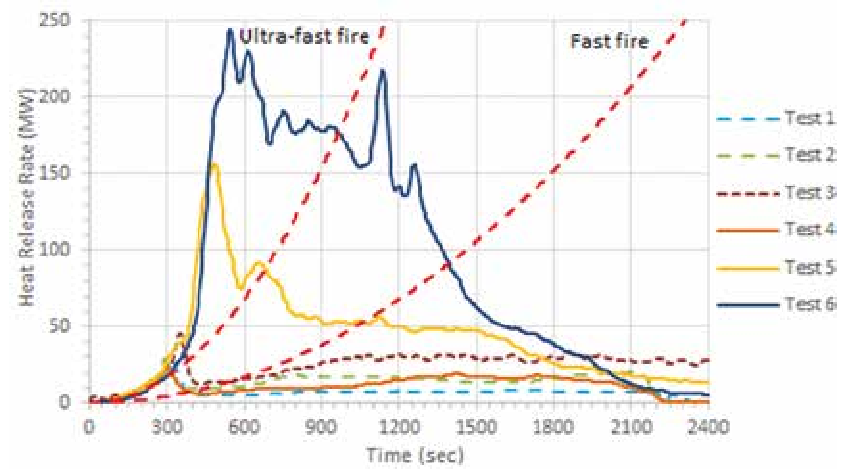
◀ Smoke control in a road tunnel with jet fans.

◣ CFD simulation of airflow in tunnel ventilated with MoJets.

▼ Overview of fixed fire-suppression systems for tunnels.

	Low-pressure deluge	High-pressure watermist	Low-pressure watermist
Water consumption density	10.2–25mm/min	2.7–4.7mm/min	3.0–4.2mm/min
Nominal zone water flow (25m x 12m)	3060–7,500 l/min	600–1,410 l/min	675–1,350 l/min
Size required for water reservoir for 1 hour with 3 zones active (75m active tunnel protection)	550–1,350m³	108–254m³	122–243m³
Water pressure at nozzles and at pumps	Nozzles: 1.1 bar Pumps: 6 bar	Nozzles: 35–80 bar Pumps: 64–140 bar	Nozzles: 10 bar Pumps: 15 bar
Riser pipes size required for a 2 km tunnel	250mm pipe	89–168 mm pipe	125mm pipe
Pump power	132kW	510–1,080kW	136kW

Fire heat release rates with and without fire suppression



Test 1 to 3: Mist system operated at 4 minutes
Test 4: One zone mist system and one deluge system operated at 4 minutes
Test 5: Mist system operated at 8 minutes
Test 6: Free burning

▲ Rize Tunnel, Turkey.

Fire suppression is also normally operated in the zones immediately upstream and downstream of the incident zone, to reduce the risk of fire spread. Such systems have been specified in Japan and Australia for decades, but are now being installed in tunnels worldwide. Standards-setting organisations such as the World Road Association (PIARC) and NFPA have recognised that fixed fire-suppression systems can have a significant role to play in reducing risks to life safety, structural integrity and operational continuity. This is particularly true for tunnels with special fire risks that require compensatory measures, such as the presence of a large proportion of heavy goods vehicles, dangerous goods or long distances between escape and intervention routes to the outside. For example, the 18km-long Fehmarnbelt Tunnel currently being constructed between Denmark and Germany will have longitudinal ventilation with jet fans and a fixed fire-suppression system installed in the road tunnel tubes.

Original specifications for fixed fire-suppression systems called for low-pressure deluge systems, with a water pressure of approximately 6 bar at the pumps, and delivering up to 25mm/min of water. Such systems have been extensively tested and approved but require very large water reservoirs and sumps (with capacities of up to 1,350m3). For refurbishment projects such as the New Tyne Crossing in Newcastle in England, such water volumes were not possible to accommodate within the limitations of the existing drainage system. Instead, a high-pressure watermist system was installed, with a designed water density of around 5mm/min.

A more recent innovation for tunnels is low-pressure watermist systems. These have the advantages of low water densities and modest power consumption requirements. VID Firekill have tested their Tunprotec low-pressure mist system in the San Pedro de Anes test tunnel in Spain, and have demonstrated that the total fire heat release from a fully loaded heavy goods vehicle can be suppressed from 243MW to 32MW using a 4mm/min water discharge rate. The Land Transport Authority of Singapore sponsored this research, and have now specified this system in their 9km-long Kallang-Paya Lebar Expressway (KPE) tunnel.

It is possible to combine the two innovations (MoJet for ventilation and Tunprotec for fire suppression) to achieve significant improvements in fire safety, while enhancing the energy efficiency and sustainability of a tunnel. An example of such a design is that of the Rize tunnel in Turkey, a road tunnel with two tubes and a length of approximately 4km. The original design had no fire suppression system and 90 jet fans, designed to generate the critical velocity for smoke control in case of a 100MW fire. With a Tunprotec low-pressure mist system, the total fire heat release rate can be reduced down to a design value of 40MW, if the mist system is operated within 4 minutes of detection. On that basis, only 20 MoJets would be required, which includes allowances for maintenance outages and fire-induced damage. This solution represents almost 80% reduction in the required number of jet fans, while enhancing the life safety, structural integrity and operational resilience of the tunnel.

The design solution for the Rize tunnel points to a possible change in the paradigm for fire safety in road tunnels. Whereas the primary means of fire protection in road tunnels was previously ventilation for smoke control, the emergent trend is to rely on fire suppression as the primary fire mitigation measure, with ventilation only being a secondary measure.

Further research and development is ongoing to further improve the sustainability of tunnels, while also enhancing their safety. For road tunnels in particular, the appropriate combination of fire suppression and ventilation is the key to achieving this objective.

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