# BENEFITS OF FIRE SUPPRESSION

Quantifying the effects of suppression on energy release. This article by **Fathi Tarada**, managing director of fire safety, risk management, ventilation and CFD consultant *Mosen* is a preview to his paper due to be published in the forthcoming International Symposium on Aerodynamics, Ventilation and Fire in Tunnels due to be held in Barcelona in September

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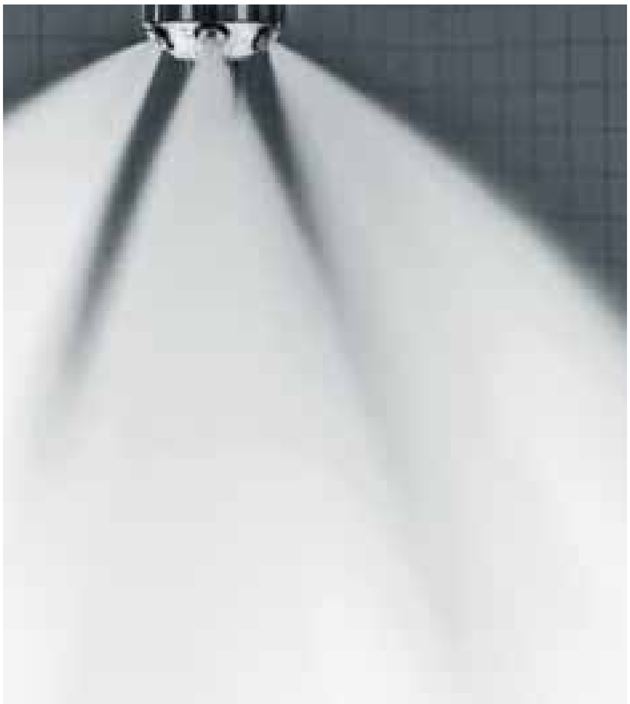
**THE FIRST** tunnel fire suppression systems in the UK were commissioned in the New Tyne Crossing in 2011, and the installation of high-pressure mist systems is currently ongoing in the Dartford Tunnels between Kent and Essex. Other tunnels in the UK are actively considering such fire suppression systems. However, with the Dartford mist systems costing in excess of GBP 8M (USD 12.5M), tunnel operators are certainly justified in asking what the benefits of fire suppression are, and whether their price tag can really be justified. ›



*Above: Fire suppression systems can drastically retard the development of a fire*

**Whether the costs can be justified** is a question that cost-benefit analysis should answer

Vehicle fires, particularly those from heavy goods vehicles (HGVs) can damage the tunnel structure and equipment, and can cause significant traffic disruption while repairs are being carried out. Recent incidents include the Brynglas Tunnel fire on the M4 near Newport, Wales in July 2011, and severe damage to the Brattli Tunnel at Tysfjord, northern Norway in January 2013. Mercifully, neither of these fires involved human casualties. However, lives have been lost in previous fire incidents including in the Mont Blanc (1999), Tauern (1999) and Gotthard (2001) tunnels.

None of these tunnels had fire suppression systems installed at the time of the incidents.

Suppression systems have the potential of reducing the intensity of any fires, so as to reduce the extent of any damage to the tunnel structure and equipment, and also serve to protect tunnel users from the effects of fire.

The Burnley tunnel fire involving three trucks and four cars which occurred in March 2007 in Melbourne, Australia caused only minimal structural damage due to the operation of a deluge system. However, three people died in the accident – two from the effects of fire, and one from multiple injuries. Arguably, the combined effect of the smoke ventilation and fire suppression systems helped to avoid a much greater loss of life in that incident.

## OBSERVATION

Although tunnel fire suppression systems have been installed in Japan and Australia for decades, detailed experimental evidence of their effectiveness in reducing heat release rates and minimising concrete temperatures had not been available. The availability of the limited test data was heavily restricted by fire suppression manufacturers who sponsored the tests. To address this dearth of information, a number of research projects have recently been undertaken. The German SOLIT2 programme investigated the performance of high-pressure mist systems, and tests were undertaken with low-pressure deluge systems, the Singapore Fire Test Programme (SFTP) sponsored by the Land Transport Authority (LTA) in Singapore.

The SOLIT2 tests were undertaken with simulated HGV loads corresponding to a potential heat release rate of up to 150MW, as well as pool fires with potential heat release rates of up to 100MW. The fire tests were conducted in the test tunnel of San Pedro des Anes, in northern Spain. Unfortunately, the publicly available SOLIT2 reports were heavily redacted for commercial reasons and do not contain any information regarding water application rates, which significantly reduces their usefulness for research and engineering design. However, some information can be gleaned from the reports.

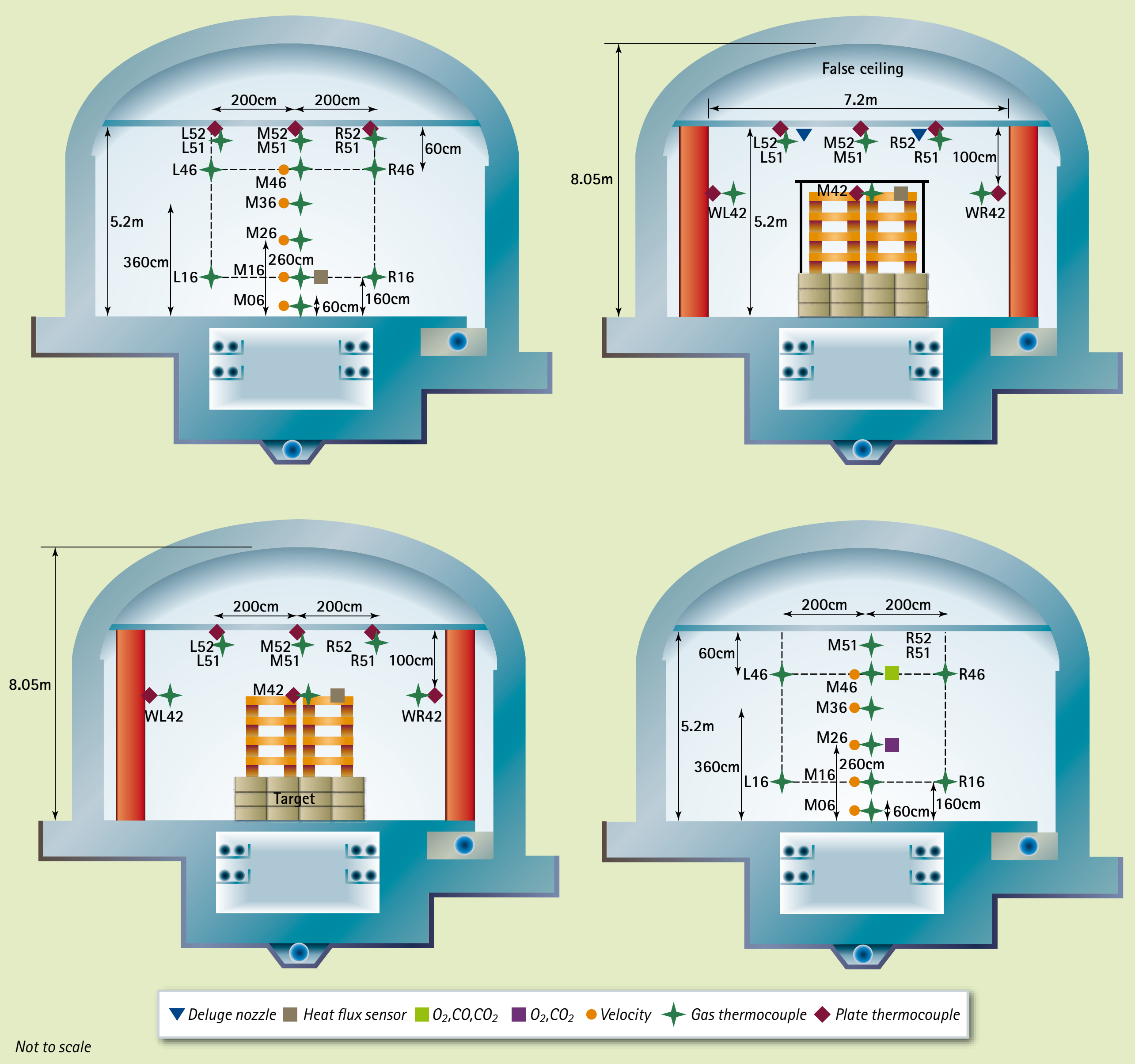
The San Pedro test tunnel has a length of 600m with a slope of one per cent. It is a two-lane road tunnel built in concrete, with a lower gallery for emergency and services, and three emergency exits. The width of the original tunnel is 9.5m with a height of 8.2m, but the tests were undertaken within a reduced tunnel section measuring 7.5m in width and 5.2m in height. The HGV mock-up was made of wooden Euro pallets with less than 20 per cent humidity. To simulate the impact of driver's cabin and solid rear doors on the ventilation conditions inside the fire load, steel plates were mounted onto the racks on the front and rear sides of the mock-up.

The SOLIT2 tests indicated that the heat release rate from an HGV fire can be limited to 30MW or less, if the mist system is operated seven minutes after ignition. Ceiling temperatures were limited to 800°C immediately above the flame zone, a

*Table 1. Large Scale Fire Test Schedule*

| Test | Test description (variation) | Discharge density (mm/min) | Nozzle type | Activation time (min) | Fire in suppression zone |
|---|---|---|---|---|---|
| 1 | Directional nozzle | 12 | Dir 180° | 4 | Centre of zone |
| 2 | Directional nozzle | 8 | Dir 180° | 4 | Centre of zone |
| 3 | Standard spray nozzle | 12 | Standard | 4 | Centre of zone |
| 4 | Standard spray nozzle* | 12 | Standard | 4 | Centre of zone |
| 5 | Standard spray nozzle | 12 | Standard | 4 | End of zone |
| 6 | Standard spray nozzle | 12 | Standard | 8 | Centre of zone |
| 7 | Unsuppressed | n.a. | n.a | n.a | Centre of zone |

*Source: Author*



*Above: Figure 1, Cross-section of the test tunnel and instrumentation set up*

value which can still lead to concrete spalling. However, ceiling temperatures at a location 15m downstream of the fire were limited to 200°C, which should not cause spalling. The air velocity through the tunnel varied during the test between 2 and 3m/s, but no back-layering of smoke was identified during the operation of the mist system.

The mist system limited the heat release rates for pool fires to less than 80MW, and ceiling temperatures to less than 700°C immediately above the flame zone. Flames spread beyond the fuel trays, and ceiling temperatures were therefore in excess of 500°C at locations 15m downstream of the fire location. The measured longitudinal air velocity was between 3 and 4m/s, but that was not sufficient to overcome smoke backlayering prior to the activation of the fire suppression system. After activation of the mist, all the smoke was blown downstream.

The SFTP was carried out at the same test facility as the SOLIT2 tests, but were concerned with the investigation of low-pressure deluge systems rather than high-pressure mist. The objective of the SFTP was to investigate the magnitude of the heat release rates and temperatures generated with and without a low-pressure deluge fire suppression system.

Detailed results from the SFTP are due to be published in the forthcoming International Symposium on Aerodynamics, Ventilation and Fire in Tunnels due to be held in Barcelona on 18-20 September 2013, but some key results will be presented here, with kind permission of the management of LTA.

The minimum dimensions of the rectangular test section at the location of the fire source were 7.3m wide and 5.2m high. At the location of the fire source, walls are constructed inside the real test tunnel to protect the concrete against damage. The resulting cross-section is shown in figure 1. Jet fans at the northern end of the portal are used to generate an air velocity in the tunnel for the entire duration of the fire test.

The effects of various fire suppression parameters such as deluge nozzle type, discharge density and activation time were investigated. The simulated heavy

*Table 2. Schedule of fire tests carried out*

| Test no. | Nozzle type | Discharge density (mm/min) | Activation at | # Pallets | Fire load |
|---|---|---|---|---|---|
| 0 (pre) | Standard | 7 | 13 min | 10 full width | Uncovered |
| 1 | Standard | 11.2 | Max HRR | 19 full width | Uncovered |
| 2 | - | - | - | 15 partial width | Covered |
| 3 | - | - | - | 15 partial width | Uncovered |
| 4 | Dir. 180° | 12.2 | Max HRR | 15 partial width | Covered |
| 5 | Dir. 180° | 12.2 | Max HRR | 15 partial width | Uncovered |
| 6 | Dir. 180° | 7.9 | Max HRR | 15 partial width | Covered |
| 7 | Dir. 180° | 7.9 | 4 min | 15 partial width | Covered |
| 8 | Standard | 7.9 | 4 min | 15 partial width | Covered |
| 9 | Standard | 7.9 | Max HRR | 15 partial width | Covered |
| 10 | Dir. 110° | 7.9 | 4 min | 15 partial width | Covered |
| 11 | Dir. 180° | 12.0 | 4 min | 15 partial width | Covered |

*Source: Author*

goods vehicles consisted of 228 pallets with 48 plastic pallets (20 per cent by volume) and 180 wooden pallets (80 per cent by volume). A longitudinal air velocity of between 2.8 to 3m/s was applied in the tunnel fire tests.

Peak heat release rates of 27 to 44MW were measured for deluge operation at four minutes, 97MW for delayed deluge operation at eight minutes and 150MW with no deluge intervention were obtained in the SFTP. This fire test series shows that the activation of deluge system at the early phase of the fire development is important as it helps to reduce the severity of the fire development during the growth phase.

In addition to the full-scale fire tests within a tunnel, LTA also sponsored a series of reduced-scale fire tests, in order to consider certain issues in more detail. The fire load in the laboratory fire tests consists of wooden and plastic pallets, with the number of plastic pallets equalling 20 per cent of the total number of pallets. In order to sufficiently represent the fuel layout as in the large-scale tunnel tests, the same stacking height (relative to the nozzles) was used as in the large-scale tunnel tests. A pallet stack height of about 3m from the floor was used, and the top of the pallet stack was thus 2m below the sprinkler nozzles.

## ENERGY ABSORPTION

Measurements were undertaken of the water flowrates and thermal energy budgets during the LTA laboratory tests. A total of 11 tests were carried out, as summarised in table 2. The heat release rate was determined using oxygen depletion calorimetry.

**25**

The maximum per cent of released energy that is abosrbed by evaporation of suppression water

After activation of the fire suppression system, some 31 to 49 per cent (average 39 per cent) of the released energy was found to be absorbed by the evaporation of water. About half of this is assumed to be absorbed by the water vapour generated in the combustion products; hence 15 to 25 per cent of the released energy is absorbed by evaporation of suppression system water.

After activation, some 25 to 55 per cent (average 38 per cent) of the released energy is absorbed by heating of the (liquid) water. The energy absorbed by heating of the (liquid) water is assumed to be partly due to energy absorption from the hot structure (walls/ceiling). As the balance should add up to 100 per cent, and the measurements add up on average to 120 per cent, about half of the heating (20 per cent) is assumed to be caused by absorption of heat from the walls and the ceiling (due to heat released earlier by the fire); hence about 20 per cent of the heat generated is removed from the setup due to heating of suppression system water.

After activation of the fire suppression system the walls are cooled by water, and this increases the rate of heat removal from the fire source. An average of 23 per cent to the total (chemical) fire heat release rate is gained from the floor,

*Below: Damaged lining in the Channel Tunnel following the 1996 fire*

walls and ceiling of the enclosure. It was estimated that the convective heat transfer represents 25 to 51 per cent (average 43 per cent) of the released fire heat release rate.

Only the convective component of heat transfer is relevant in terms of the dimensioning of a tunnel ventilation system. This is because the thermal buoyancy of the hot gases issuing from a fire is controlled by convective heat transfer, i.e. hot air rising. The critical velocity for smoke control is dependent on buoyancy effects, as described by the ratio between the inertial and buoyancy forces. Since only a fraction of the heat transfer in suppressed fires flows out via convection, it follows that appropriate allowances may be made in the relevant calculations, including estimates of critical velocity and the setting of boundary conditions for aerodynamic calculations.

For unsuppressed fires, it is common practice to assume that 70 per cent of the fire heat release rate is convectively transported, with the balance being lost due to radiation to the surrounding environment and to the fuel source. Calculations of the critical velocity for smoke control are typically based on the convective component of fire heat release rate only.

It was observed that the convective heat transfer was generally less than 50 per cent of the suppressed fire heat release rate.

Depending upon the risk assessment process undertaken, and the degree of confidence attached to the performance of the fire suppression system, a significantly lower value for convective fire heat release rate may therefore be assumed for suppressed fires.

## FINAL THOUGHT

Fire suppression systems in tunnels are no panacea, as the recent false discharge in the Tyne Tunnel in Newcastle, UK has demonstrated. However, their potential utility in reducing the risks to tunnel structures and users, and to minimise downtime following an incident, are clear.

Whether their price tag can be justified is a question that a careful cost-benefit analysis should answer. Ultimately it will be the client that drives the uptake of these systems

Above: *A wrecked carriage following the 1996 Channel Tunnel fire*