# Create a safer tunnel and increase ROI while utilizing the full compensating effects by installing an active water-based Fixed Fire Fighting System (FFFS) in transport applications.

Johnny Jessen VID Fire-Kill (TUNPROTEC®), June 26th 2018


## Abstract

We, as well as other vendors, have experienced an increasing interest in installing a Fixed Fire Fighting System for tunnel projects, but still we find that several countries and stakeholders are very reluctant to install a FFFS, reasons could be several e.g. traditions, lack of knowledge re. how an FFFS operates and work and not least how a FFFS can compensate other safety measures like the ventilation system, passive fire protection or positions of emergency exits, traffic intensity, hazard goods etc.

Fixed Fire Fighting Systems have over the last decade been exposed to significant number of full scale tunnel fire tests and research to an extend that far exceeds what other safety systems like e.g. ventilation systems and detection systems have been exposed to, especially in Europe, and by that providing a lot of evidence regarding the effect of an FFFS.

This paper will provide some of the most recent research data regarding the effect for a low pressure watermist system in a tunnel environment; It will also describe the differences and similarities between high pressure and low pressure watermist and deluge/sprinkler FFFS.


*Keywords: Fixed firefighting systems (FFFS), high and low pressure watermist, deluge, sprinkler, tests & newest research data obtained, HRR (heat release rate), ventilation system, passive fire protection.*

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# 1. Introduction to Fixed Fire Fighting Systems (FFFS)

A Fixed Fire Fighting System (onward referred to as FFFS) is a system that in an active way fights a fire. Such systems are typically also called water based fire fighting systems or suppression systems. The most common FFFS for tunnels are either deluge (low pressure) or watermist (in high or low pressure).
Both technologies work in deluge operation, dividing the tunnel into fire zones typically 20-30 m of open nozzles activated by opening a section valve. Both technologies are using some of the same fire fighting methods, but also some differences which later described in this paper.

Japan was the first country to installing an FFFS more than +50 years ago together with Australia, who by default install FFFS in all their tunnels. Japan together with Australia and USA prefers deluge systems, the origin of deluge system comes from the standard sprinkler applications.
In European tunnels (whereof Sweden is an exception) watermist is the preferred technology.

## 1.1. Choosing technology

When choosing for which technology to apply in a given tunnel or infrastructure project, the client or consultant normally expects that the system applied is fully tested and will work in case of a fire when activated and can be maintained with minimum concern for traffic users. That must be the expected minimum criteria expected for an FFFS.

When comparing the three technologies there are some similarities but also some differences worth considering before choosing.

## 1.2 Deluge/sprinkler

Deluge/sprinkler systems are usually using open sprinkler heads/nozzles, applying typically;
Nozzles: Min. 1.1 bar
Pumps: 6 bar

Deluge technology can be described as a system operating with a relatively low pressure distributing water in larger droplet sizes (> 1mm) with low kinetic energy when discharged by the nozzle.

Deluge/Sprinkler offers;
- Robustness,
- Higher water consumption than high pressure watermist,
- Less maintenance intense than high pressure watermist,
- Lower component costs, using typically coated steel pipes (PN16),
- Can share water-main with hydrant,
- Can share fire-pumps with hydrants.

### 1.3 Watermist (high pressure)

Watermist systems using open sprinkler heads/nozzles, applying typically;
Nozzles: 35-80 bar
Pumps: 64-140 bar

High pressure watermist technology can be described as a technology distributing the water in smaller droplets due to the high pressure applied +35 bar resulting in high droplet energy/heat absorption and evaporation rate.

High pressure watermist offers;

- Smaller pipe dimension than a deluge system,
- Less spatial requirement than a deluge system,
- Significant lower water consumption than a deluge system,
- More complexity and Less robust than a deluge system,
- Require more maintenance service/sequences than a deluge system,
- A costlier system than deluge.

### 1.4 Watermist (low pressure)

Nozzles: 10 bar
Pumps: 15 bar

Low pressure watermist technology can be described as a technology which utilizes or bridges the best from both the deluge-/ and high pressure watermist technologies.

Low pressure watermist offers;

- Smaller pipe dimensions and spatial requirements as from high pressure,
- Simplicity and robustness from deluge,
- Low maintenance requirements as from deluge,
- Low water consumption as from high pressure watermist,
- Can share fire-pumps with hydrants as from deluge,
- Cost efficient = can utilize standard PN 16 components as from deluge,
- Can share water-main with hydrants as from deluge.

Both high-/low pressure watermist systems operate with a relatively large distribution of smaller droplet sizes (< 1mm) with high kinetic energy or velocity when discharged by the nozzle, enable to fill the full tunnel cross-section with a 3D water spray/mist.

**Firefighting methods watermist:**
Watermist systems works with a significant less amount of water when fighting a fire, watermist is applying several firefighting methods make it equal or better than deluge/ sprinkler solutions, but with significant less water consumption.
Watermist uses a combination of wetting the surfaces, distributing smaller droplets which very fast can absorb more energy/heat from the fire than the larger droplets distributed by deluge, provides efficient oxygen depletion at the fire source.

**Firefighting methods deluge/sprinkler:**
Deluge systems operate with a relatively bigger distribution of larger droplet sizes (> 1mm) with low kinetic energy when discharged by the nozzle. As an effect of that a deluge system normally works with the principle to apply a "lot" of water to the fire surface/source also called wetting the surfaces and by that suppress and cools the surface.

## 2. Tunnel Fires

Typical fires in a tunnel are normally deep seated solid (Class A) fires or flammable (Class B) fires, and as such very difficult extinguishing. It's important to understand that a tunnel fire is very different to a building fire, due to the nature of the fire load, typically an HGV covered with tarpaulin and as such the water have limited access to the seat of the fire until the cover has opened up due to the exposure of flames or temperatures/heat.

Typically, a modern tunnel safety strategy operates with the idea or concept that rescue workers or fire fighters can quickly access the tunnel in case of a fire, meaning that back-layer and temperature should be controlled prior to access the tunnel.

### 2.1. Stand-alone ventilation system vs. design HRR fires

The clear majority of road or train tunnels today are typically protected or depends on a stand-alone ventilation system can make tenable conditions for evacuation and access for rescue workers and fire fighters to quickly enter the tunnel and evacuate and/or extinguish the fire.
However, in several cases in recent time and in the past this strategy hasn't been sufficient and coursed substantial loss of life and tremendous damage and costs to the tunnel structure and close down in significant period of time, up to months or years of highly important infrastructure network.
The reason for those incidents and/or the ventilation system inability to handle such bigger fires with substantial high HRR output is due to the fact that in many cases, consultants or tunnel operators has underestimated the HRR output or development of an unsuppressed fire in a tunnel environment during the risk analysis.

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The table shown below are international accepted HRR output which consultants uses for reference during the risk analysis as a help tool to determine design fires.
Often in specifications for concrete tunnel projects we see design fires e.g. 30, 50 or 100 MW, however with below table in mind, and if the tunnel is allowed for mixed traffic, then one should not wonder why a ventilation system gets overwhelmed and not able to handle the fire situation.

| HRR MW | Road vehicles | Rail vehicles | Metro vehicles | Fire Boundary |
|---|---|---|---|---|
| 5 | 1 – 2 cars | | | ISO 834 |
| 10 | Small van, 2 – 3 cars ++ | Electrical locomotive | Low combustible passenger carriage | ISO 834 |
| 20 | Big van, public bus, multiple vehicles | | Normal combustible passenger carriage | ISO 834 |
| 30 | Bus, empty HGV | Passenger carriage | Two carriages | ISO 834 |
| 50 | Combustible load on truck | Open freight wagons with lorries | Multiple carriages (>2) | ISO 834 |
| 70 | HGV load with combustibles (4 tons) | | | HC |
| 100 | Average HGV | | | HC |
| 150 | HGV loaded with easy comb. (10 tons) | | | RWS |
| >200 | Limited by oxygen, petrol tanker, multiple HGVs | Limited by oxygen | | RWS |

Table 2.1. HRR outputs

## 2.2. Facts to be considered

So, even if a ventilation system is correct dimensioned to handle a big fire with a major HRR peak, then also the ventilation velocity has a great impact on fire growth rates (1), velocities above 2,5 m/s will increase the rate or speed at which the HRR will rise by 50% compared to moderate or lower ventilation speed – higher ventilation velocities are normally applied, when a back layer must be controlled/removed!

The production of CO - $CO_2$ and toxic substances rise linearly with the increase of the HRR. The FGR of a large fire increases dramatically when it is not controlled at approximately 5 MW – beyond that the FGR accelerated rapidly at 16,4–26,3 MW/min and a fire can quickly get out of control and easily exceeds the capacity of a standalone ventilation system and an overwhelming ventilation system can`t neither prevent a back-layer upstream, neither control or reduce temperature and as such not prevent fire spread and such scenario`s will not enable rescue-/firefighting teams to access the tunnel .
If an HRR of 75 MW fire is reached, temperatures downstream make self-evacuation impossible.

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## 2.3. Some examples of catastrophic fires with a stand-alone ventilation system.

| CATASTROPHIC TUNNEL FIRES W/O (FFFS) | | |
|---|---|---|
| **Fire Cause** | **Location** | **Loss/Damage** |
| A HGV (Truck) with flour and margarine caught fire | Montblanc Tunnel Italy/France | • 41 people died<br>• €350-450 mio + €500 mio in transport system downtime |
| A HGV (truck) crash caught fire | Gotthard Tunnel Switzerland | • 11 people died<br>• €6 mio in repair costs |
| Fire in a chemical hauling HGV (truck) | Euro Tunnel UK/France | • €60 mio in repair costs<br>• €200 mio income losses |

Ref.: Catastrophic Tunnel fires, SP Report 2004-05 FD

## 2.4. Calculated estimated maximum HRR Qmax MW (2) including some of the above catastrophic tunnel fires.

| Accident, year | Vehicle type | Tunnel cross-section ($m^2$) | Estimated total heat content, $E_{tot}$ (GJ) | Estimated maximum HRR, $Q_{max}$ (MW) | Estimated time to $Q_{max}$ | Estimated fire duration, $t_2$ | Fuel or ventilation-controlled tunnel fire |
|---|---|---|---|---|---|---|---|
| Baku 1995 | 2 metro coaches | 28 | 80-100 | 70-90 | 10-15 min | 30-50 min | Fuel controlled |
| Kaprun 2001 | Funicular train | 9-10 | 20-30 | 15 - 20 | 15-20 min | 45-60 min | Fuel controlled |
| Channel tunnel 1996 | 10 HGV | 45 | 2200 | 370 | 1 h | 2.5 (3.4) h | Ventilation controlled |
| Mont Blanc 1999 | 15 HGV, 9 cars* | 50 | 5000-7000 | 300 – 380 | 2-3 h | 9-13 h | Ventilation controlled |
| Tauern 1999 | 16 HGV, 24 cars | 45 | 4000-4500 | 300 – 400 | 2-3 h | 7-10 h | Fuel controlled |

Ref.: Catastrophic Tunnel fires, SP Report 2004-05 FD

| CATASTROPHIC TUNNEL FIRES W (FFFS) | | |
|---|---|---|
| **Fire cause** | **Location** | **Loss/damage** |
| 3 HGV`s and 4 cars crashed (resulted in an explosion +fire) | Burnley Tunnel Australia | • 3 people died<br>• Very limited damage and repair cost |

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MONT BLANC TUNNEL

BURNLEY TUNNEL

The Burnley tunnel fire in Australia in 2007 had a potential HRR comparable to some of the other named catastrophic tunnel fires showed at 2.3, but due to the ventilation-/ Fixed Fire Fighting Systems interaction and quick activation and operation the fire was suppressed and controlled, so that the HRR peak was never reached and casualties (due to the fire) was prevented and the tunnel structure was intact, the tunnel was opened in less than 3 days after the fire.

## 3. Compensating Effects or Potentials by Installing a Fixed Fire Fighting System

It is a known fact that an FFFS or suppression system can substantially reduce fire heat release rates HRR for a tunnel fire, but the practical application or potential for compensatory effects of the installed FFFS is less known, or in many cases, not yet fully utilized.

### 3.1 The mechanisms of a FFFS or fire suppression system

After activation of a FFFS/Suppression watermist system it will affect the fire through(3);

- Pyrolysis inhibition through cooling and oxygen deprivation
- Smothering of combustion with liquid and water vapour
- Cooling the hot plume through latent heat of evaporation
- Prevention of fire spread through cooling of neighboring surfaces

Fire Heat Release Components;

- Convective
- Radiative
- Latent
- Water heating
- Superheating

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### 3.2. Resulting fire heat release rate

With above omponents in mind backed up by full scale tunnel fire testing proves that installing a FFFS can reduce a given design fire significant as an example a 100 MW design fire was chosen and with reference to below figures (Without Fire Suppression) and (With Fire Suppression) will give the following result.

| Without Fire Suppression | | |
|---|---|---|
| Convective | ~ | 70% of fire heat release rate |
| Radiative | | 30% of fire heat release rate |

| Witht Fire Suppression | | |
|---|---|---|
| Convective | ~ | 50% of fire heat release rate |
| Radiative<br>Latent<br>Water heating<br>Superheating | } ~ | 50% of fire heat release rate |

### 3.3. Resulting Fire Heat Release Rate for ventilation system or other compensation

- Unsuppressed HRR = 100 MW
- Suppressed HRR = 40 MW
- Suppressed convective HRR = 50% of 40 MW = 20 MW

Above values opens up for substantial reduction for cost savings by reducing number of jet fans, ventilation critical velocity, change of a transverse or semi transverse ventilation system to a longitudinal system, reduce or avoid smoke extraction system etc..

### 3.4 Reduce or avoid tunnel fire protection or lining

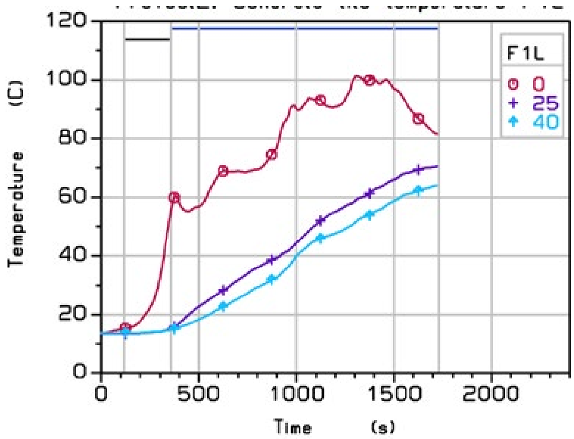
Due to a watermist system ability to offer immediately temperature reduction and control after activation, enable engineers and consultants to either reduce or avoid protective fire protection layer or insulation/lining when installing a FFFS.

### 3.5. Other options for cost savings

Also, during the risk analysis, there are plenty of options to implement significant cost savings when installing a FFFS e.g.;

- Emergency exists
- Higher traffic intensity
- HGV hazard goods allowed

### 3.6. Structural protection by a FFFS




Graph 3.6. showing a structural temperature test in a concrete tile installed nearby the fire source

Graph 3.6, shows temperatures obtained for a newly completed full-scale tunnel fire test with our system, which confirms that our systems are able to cool the temperatures in the tunnel concrete structure. The test is performed on a concrete tile mounted to the ceiling above the fire source and the measurements were carried out by measuring at 3 levels inside the concrete tile, 0 = (surface), at 25 mm, and at 40 mm. In all measurements, the concrete temperature was well below NFPA 502 threshold values.

The above test has been performed to prove that we do not exceed NFPA 502 thresholds:

- Ceiling surface temperature shall not exceed 380°C (As per NFPA 502 recommendation), to demonstrate that there is minimum spalling, which may lead to progressive tunnel collapse
- Temperature of steel reinforcement within the concrete shall not exceed 250°C (As per NFPA 502 recommendation)
- To demonstrate that there is minimum spalling, which may lead to progressive tunnel collapse.

That leaves plenty of room for less protective fire protection or maybe even avoiding additional passive fire protection.

Fig. An HGV fire in a tunnel

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## 4. Conclusions

Both the High Pressure and Low Pressure Watermist systems together with Deluge have undergone numerous full scale tunnel fire tests, which particular is performed by the European vendors.
So, there is a substantial amount of fire test data and research results available which can be published proving and witnessing FFFS ability to minimize risks and protect the asset.

## 5. Future Work and Research

It is a known fact that Fixed Fire Fighting Systems can provide significant reduction of the size of a fire when activated, traditionally the reduction factor have until today been app. 50%, however newest research and test in 2018 has shown substantial higher reduction factors up to 70-80% reduction of the potential HRR Qmax (MW). We plan to publish more in detail about this tests and research in the autumn, but the final result can highly impact the decision process positively by utilizing those new data for compensation effects and provide very favorable ROI.

Also, the fact that alternative fuel cars gets more and more popular, there is a lack of research and test in relation to battery driven vehicles and fires in tunnels, so this is definitive an area where we as a company will allocate resources for further investigation and test.

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