IMPROVING VENTILATION AND PASSIVE PROTECTION WITH FFFS

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ABSTRACT

This paper discusses the efficiency of fixed fire fighting systems (FFFS) in combination with other safety measures, particular tunnel ventilation systems and passive fire protection in road tunnels. This is done by referring to the experimental data from full scale fire tests of the SOLIT² (Safety of Life in Tunnels) project. The SOLIT² project was carried out 2009 - 2012, having so far the largest fire test program, focusing on using FFFS in combination with other safety measures.

The presented results in the paper demonstrate that ventilation systems can be compensated by FFFS within certain limits. Test results from the comparison of 30 MW and 100 MW heat release rate (HRR) of class B fires with semi-transversal ventilation are used to demonstrate the effect of FFFS to the ventilation design criteria.

The experimental results show that a ventilation system designed for 30 MW HRR without FFFS can control even a 100 MW fire with FFFS. The reasons for this are discussed in the paper. Additionally other important aspects of FFFS in conjunction with passive fire protection will be shortly discussed in the paper as well.

Keywords: Fixed firefighting systems (FFFS), ventilation systems, SOLIT² research program

1. EXPERIMENTAL RESULTS

1.1. SOLIT² Research Project

The experimental results shown in this chapter have been measured as part of the SOLIT² research project. Test program included over 31 full scale fire tests in order to test the efficiency of FFFS in combination with the fire ventilation system in road tunnels. Half of the test fires were executed as class A (solid) fires involving complete lorry-loads (fire load consisting wooden pallets with a potential heat release rate [HRR] of over 100 MW) and the other half as class B pool fires (fire load consisting diesel fuel with HHR ranging from 30 MV to over 100 MW).

The research project "Safety of Life in Tunnels 2" (SOLIT²) started in 2009 with the aim of investigating the interaction between FFFS water mist fire suppression systems and other road tunnel safety equipment as e.g. the fire ventilation. The project ended in 2012 and was partly funded by the federal Ministry for Economics and Technology as a result of a decision by the German Bundestag. The results and reports are publically available from www.solit.info.

1.2. Fire tests arrangements

Fire test tunnel

Used TST test tunnel is only built for test purposes and has got a total length of 600 m. The shell construction has a horseshoe cross-section, typical for road tunnels (9,55 m wide and 8,10 m high). But for the almost whole length of the tunnel, an intermediate ceiling is arranged, which limits the height to 5,2 m. This ceiling serves to build up an exhaust duct for the semi-transversal ventilation system.

In order to unify the naming of different measurement areas, the middle of the fire load was defined as “zero” for all distances along the tunnel axis. In the direction of the prevailing longitudinal ventilation direction, all positions were called “D” for downstream plus the corresponding distance in “m”. Against the direction of the air flow, all positions were called “U” for upstream plus the corresponding distance in “m”.

Ventilation system

The test tunnel is equipped with systems for longitudinal and semi-transversal ventilation. The longitudinal one is powered by six jet-fans attached to the tunnel ceiling within the horseshoe section in the beginning of the tunnel, velocities between 1 to 6 m/s can be achieved. The semi-transversal ventilation system is built up in a ventilation station with two axial fans, which can extract 120 m^3/s. This air flow will be extracted through 14 dampers, which are installed in the intermediate ceiling between the tunnel and the exhaust duct above; each damper has a cross-sectional area of 1,5 m^2. This set up of the semi-transversal ventilation is designed to exhaust the smoke volume of a fire with a HRR of 30 MW.

FFFS

For the tests a fixed firefighting system, type high-pressure water mist, was installed in the test zone over a length of 60 m covering the tunnel from D30 (30 m downstream) to U30 (30 m upstream of centre of fire load). The two nozzle branch lines of the system were fixed to the intermediate tunnel ceiling and were fed via a main supply line. The water supply was achieved by diesel driven pumps, set up in a container beside the tunnel fed by a 500 m^3 water storage. The pressure and the flow rate of the pump were adjustable by controlling the rpm’s of the diesel engine. However, all major layout parameters of the water mist system were corresponding to a real installation in a similar tunnel, as e.g.:

- Type of the nozzle (Shape, K-factor, etc.)
- Nozzle layouts
- Angle of the nozzles regarding the vertical axis
- Distance of the nozzle to the fire load/carrier
- Pressure at the most remote nozzle

Measurement system

In order to measure and register all relevant parameters during a fire test, a measurement system with a total of 152 sensors was set up. Measurement values from following type were recorded every two seconds:

- Air humidity
- Air speed
- Air temperatures
- Gas concentrations (CO, CO_2, O_2)
- Heat Radiation
- Material temperatures
- Flow rate of the water mist system
- Pressure of the water mist system

In order to measure the influence of a FFFS on material temperatures, a concrete specimen, containing five thermocouples with different distances to the specimen surface, was installed underneath the ceiling. This specimen was positioned 7 m behind the fire load.

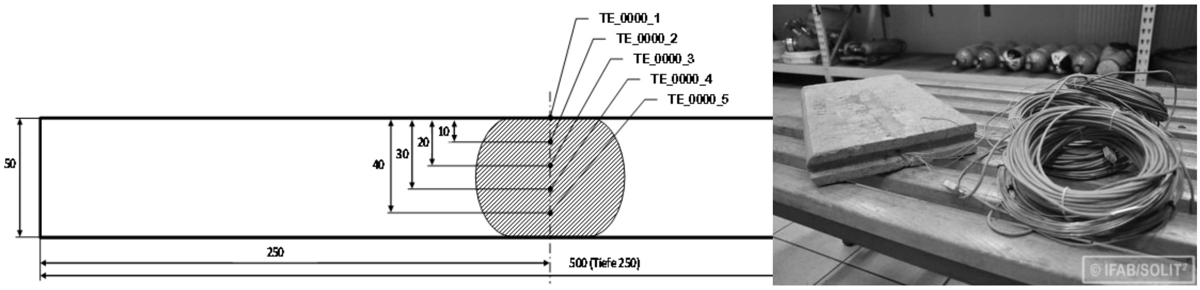


Figure 1: Sketch and photograph of a concrete specimen and assembled material thermocouples

Class B / pool fire load

In order to obtain a uniform class B fire with a predictable HRR, multiple steel trays were arranged together to form one continuous surface. Depending on the required HRR (e.g. 30, 60 or 100 MW) the according number of 40 cm high pools were arranged together and pre-filled with a 30 cm layer of water in order to protect the steel trays. The required amount of diesel oil was put on top of the water and 1 litre of petrol was used to enable the ignition procedure.

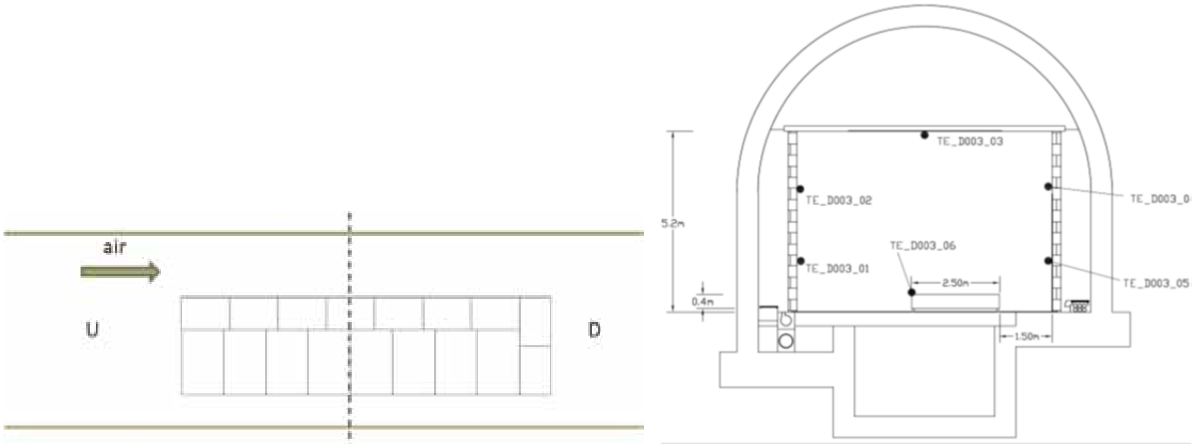


Figure 2: Pool arrangements for exemplary 100 MW fire test

Class A / HGV fire load

The geometry of this certain class A fire scenario was created to reproduce a typical heavy goods vehicle or especially a trailer. Wooden euro pallets were stacked on a 1,5 m height platform. The fuel load was covered with a truck tarpaulin. In total 408 pallets were arranged and totaling to approximately 9600 kg and 140 GJ energy content. The ignition of the fuel was done with two pans of gasoline representing a fire breakout at an overheated brake in the front part of the fire load. In that case the FFFS was activated approx. 11 minutes after ignition regardless of the measured HRR.

1.3. Test Results Class B fire - influence on ventilation

In the following the effectiveness of a water mist FFFS in conjunction with emergency ventilation is demonstrated with test results of a class B fire, which had an actual HRR of 100 MW. This certain fire load was not intended to extinguish, it was intended to have a constant energy output to show the influences on ventilation. The dimensioning of the ventilation system was configured to cope with a 30 MW fire.

After the ignition of all the 17 pools, the fire developed fast as known for pool fires. The HRR reached the 100 MW after 90 seconds, the delay occurred because of the traveling time of gases from the fire location to the gas concentration measurement in D45, where the HRR calculation was executed. The temperatures underneath the ceiling rose up to 1000 °C in the fire zone within 60 seconds after ignition.

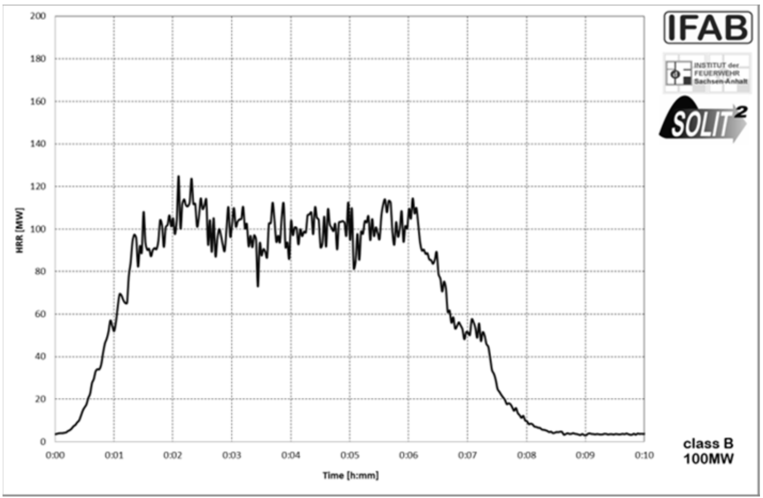


Figure 3: *Heat release rate for a 100 MW class B fire test*

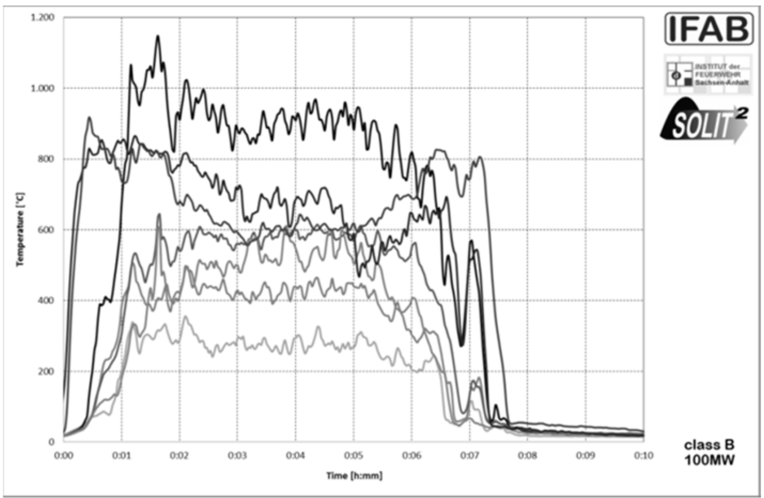


Figure 4: Temperatures near the fire zone at different heights during a 100 MW class B fire test

In that time, the smoke volume produced by the fire was higher than the volume, which could be managed by the combined ventilation system, although the extraction via the semi-transverse ventilation was already running as the fire was ignited. The longitudinal ventilation velocity was slower than the critical velocity, which resulted in the observed "back-layering" phenomenon. This means that hot fire gases moved against the longitudinal flow of 3 m/s and caused a thick layer of black smoke in the upper sector of the tunnel on the upstream side of the fire. This observation could be further documented by the increased temperatures in the upper section (in 5 m height, just underneath the tunnel ceiling in 5.2 m) of the tunnel cross section in 15m distance (upstream) of the fire load centre.

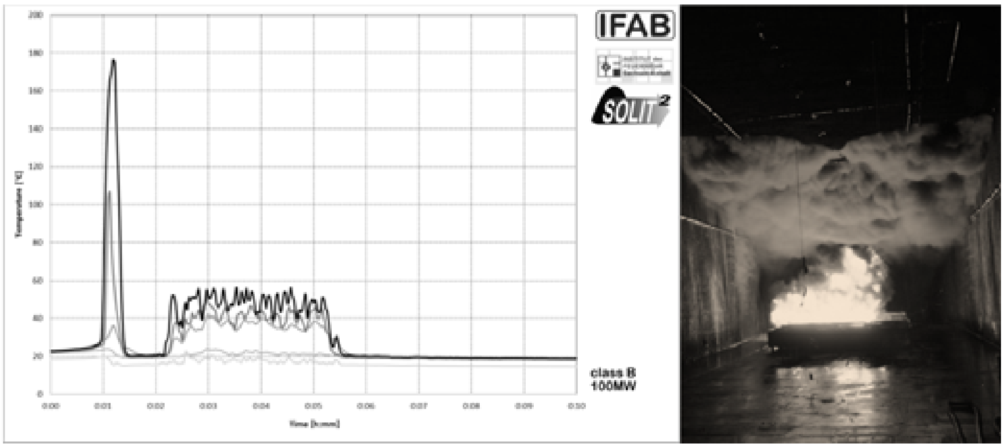


Figure 5: Temperatures 15 m upstream due to “Back layering” during a 100 MW class B fire test

Furthermore, most of the smoke was led throughout the main tunnel, which was documented by the measurement in D215. The air flow direction was positive and directed downstream with the longitudinal ventilation, the temperatures were higher than the ambient temperatures, which means that hot smoke was led to the end of the test tunnel and out through the portal.

The activation of the water mist FFFS was 60 seconds after ignition of the first pools and reached its full flow rate and system pressure after 100 seconds. After activation of the FFFS; the 100 MW pool fire was now within a very short time manageable with the combined ventilation system designed for 30 MW fires. The smoke output of the supressed fire was now lower than the extraction flow rate of the fire ventilation system (120 m³/s), which was documented by the fact that back-layering disappeared and negative and upstream air flow occurred on the downstream side of the fire at D215 near to the end of the tunnel. This means that the exhaust volume was adequate to discharge the produced smoke volume and even more fresh air, which was drawn into the tunnel.

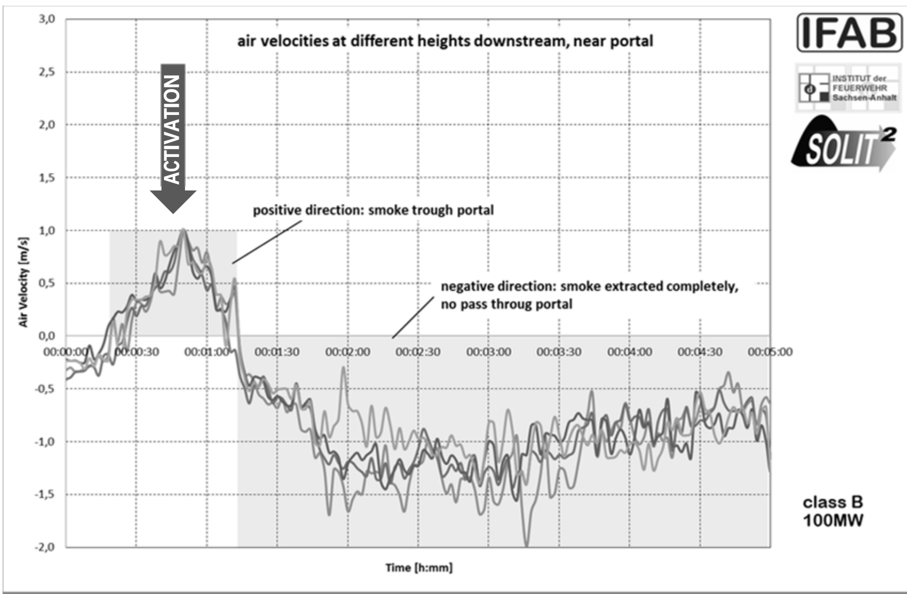


Figure 6: Air velocities near the downstream tunnel portal during a 100 MW class B fire test

1.4. Test Results Class A fire - influence on concrete specimen

The figures 7 and 8 illustrate the released heat during a class A fire and the gas temperatures under the ceiling right behind the fire load. Additionally, the material temperatures in the arranged concrete specimen at different material depths can be seen.

The material temperature directly below the concrete surface (0,2 cm below the concrete covering) reaches a maximum of 320 °C after 32 min. The other material temperatures, particular the temperature with a concrete cover of 1cm) do not reach the critical temperature of 300 °C at any time. It can be assumed that the higher temperature increase gradient, just before the activation, will develop with more serious consequences for the material if the FFFS will not be activated.

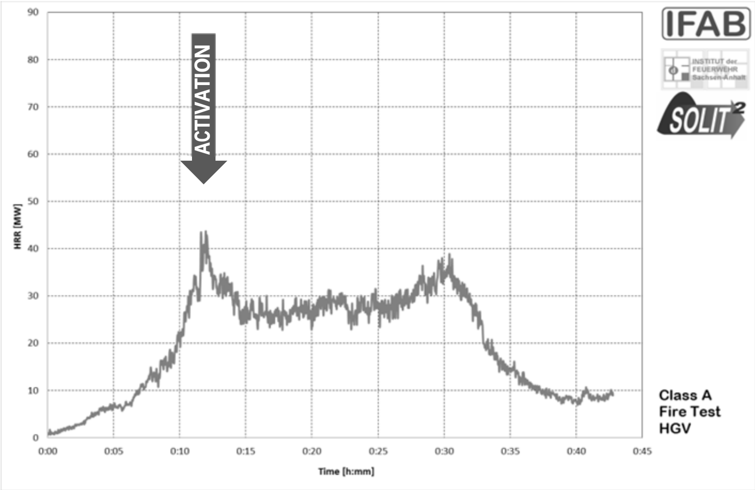


Figure 7: HRR during a class A fire test with activated FFFS

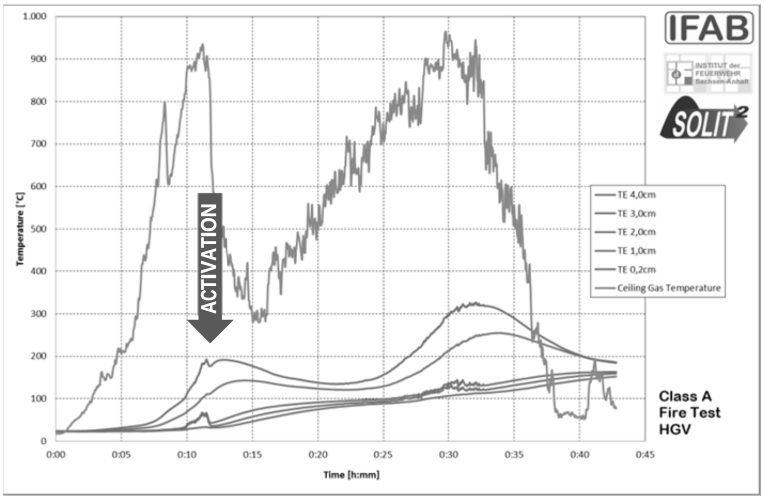


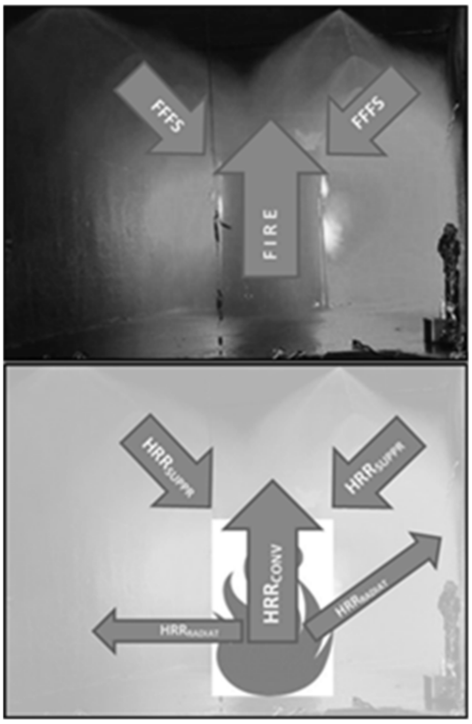
Figure 8: Material temperatures of a concrete specimen and ambient gas temperature

2. INTERFACE BETWEEN FFFS AND OTHER SAFETY MEASURES

The interface between FFFS and ventilation is relatively well studied with experimental tests. The positive impacts have been presented for example by Leucker & Kratzmeir („Brand-versuche zu Wassernebel-Brandbekämpfungsanlagen“, Tunnel 8/2011). The possibility is given to downsize ventilation system design in new built tunnels or upsize the capacity of existing ventilation in refurbishment project when FFFS is applied. This is also accepted by e.g. NFPA 502, 2014 edition. When the interface between ventilation system and FFFS is discussed, it can be divided into two aspects, FFFS impact to design fire size and FFFS impact to convective heat transfer. These are shortly explained in the following.

2.1. FFFS and impacts to convective heat transfer

The total heat release rate, $HRR_{TOTAL,}$ can be divided into sub parts, which define the portion of HRR that the entire tunnel system, particular the ventilation needs to be able to cope with it.



The total HRR is also often called a chemical HRR that is created during the combustion of fuel. A part of the total heat release rate will be absorbed by the environment, this part of HRR is generated in the form of heat radiation and is therefore called HRR_{RADIAT}. In the moment the FFFS is started, a second part, much more significant, will be absorbed by the firefighting agent. This part is called HRR_{FFFS} . The FFFS can absorb a significant part of the energy depending on the flow rates used and portion of evaporation. The now remaining energy of combustion will be transferred by combustion gases and further by surrounding air. This convective HRR_{CONV} is the effective HRR, which is used to size the ventilation system and to choose any structural protection measures.

$$\mathrm{HRR_{TOTAL}\ (HRR_{CHEM}) = HRR_{RADIAT} + HRR_{FFFS} + HHR_{CONV}}$$

The impact of FFFS in terms of cooling and absorbing the energy depends on the FFFS type and flow rates. The most important one is the evaporation rate of the system as it defines the cooling energy.

The evaporation of water absorbs the most energy; therefore, water evaporation mass rate is in the decisive factor when the effect of a particular FFFS is calculated for the total HRR. When different FFFS are compared, smaller droplet sizes provide much larger reaction surface and therefore provide more effective evaporation. This implies water mist systems are more effective in cooling because of higher evaporation rate. It can be partly compensated with considerably higher flow rates of deluge systems.

2.2. FFFS and the ventilation design fire size

Previous research projects have shown that FFFS are very effective to fight and suppress class A fires to a portion of size compared to sizes of fires being unsuppressed. This is the most important impact for the ventilation system as the initial design parameter in terms of HRR can be significantly reduced. For example, SOLIT[2] research project results have shown that heavy goods vehicle (HGV) fire loads with over 150 MW potential HRR were suppressed with FFFS to maximum 20 - 40 MW HRR. If a design fire is suppressed to a smaller HRR value, this can be utilised when dimensioning the ventilation. The design HRR can therefore be significantly reduced compared to fires without FFFS. A very important aspect is that a typical design HRR for ventilation systems is given assuming that only one vehicle is involved in fire. There is a very likely possibility that fire will spread to other vehicles during the self-rescue phase in tunnels. Then the design fire had to be adapted. When applying a FFFS, it is noticed that the fire spread onto other vehicles can be limited when dimensioned correctly.

3. SUMMARY

FFFS can reduce the potential HRR by suppressing and controlling fire size to a portion compared to a free burning fire. Furthermore, FFFS fights against the output of fire, especially convective heat transfer, which is the primary design aspect for other safety measures like ventilation or structural protection. FFFS can therefore impact positively the ventilation system design. A favourable influence on material temperatures can be demonstrated as well.

FFFS, especially water mist systems, have been tested experimentally in full scale fire tests for demonstrating the theory in practice. Presented results from SOLIT research projects showed that ventilation system design for a 30 MW design fire was able to cope with 100 MW pool fire when FFFS was applied. FFFS will be seen more in future as the mitigation method to assist ventilation designs.

Common FFFS apply water, and their performance is strongly related to used application rates, nozzle characteristics (droplets sizes) and lay-out. Water mist systems generally use far less water and work more in gaseous level, whereas deluge system apply more water and work on surface basis. Both systems have been used in real tunnels for longer times.

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