THE IMPACT OF FIXED FIRE FIGHTING SYSTEMS ON TUNNEL SAFETY – THE BURNLEY INCIDENT IN A CURRENT THEORETICAL PERSPECTIVE

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ABSTRACT

Renewed interest in FFFS has resulted in new scientific data on the effectiveness of FFFS and its interrelationship with ventilation, incident detection, water application rates and FFFS type. When this new data is compared with the real experience in the Burnley tunnel fire of 2007 the results appear consistent.
Keywords: Fire, ventilation, deluge, mist, FFFS, safety, asset protection

1. INTRODUCTION

Fixed fire fighting systems (FFFS) are the subject of renewed interest following recent recalculations of fire size and a series of extreme tunnel fire events. FFFS have been used extensively in Japan for more than 40 years and are also found in all of Australia's congested urban road tunnels.

However there remains little theoretical data in the literature about their performance. Recent investigations by both FFFS vendors and researchers are finally revealing some of the details of how FFFS work and how to optimise them in a tunnel.

The fatal Burnley Tunnel incident in Australia of 23 March 2007 provides a rare insight into the effectiveness of these fixed fire fighting systems. Unfortunately most of the technical details of the Burnley Incident remain secret. The detailed investigation report is subject to a *legal suppression order* and the "Report to the Victorian Coroner, The Fatal Burnley Tunnel Crashes Melbourne, Victoria, Australia (Arnold Dix 2008) cannot be made public. This paper uses evidence from the Supreme Court criminal proceedings of mid 2009 which is not suppressed to reveal some of the events of 2007.

Although it must be conceded that the statistical significance of the Japanese and Australian experience is unclear, neither Japan nor Australia has experienced a catastrophic tunnel fire despite numerous tunnel fire incidents. The Burnley fire provides a critical insight into how fires in Japanese and Australian tunnels are managed.

2. NEW LEARNINGS

Recently published literature is providing insights into the effects of FFFS and how to optimise its integration into tunnel safety systems.

2.1. Unshielded Fire Growth

Large scale tests by SP Technical Research Institute of Sweden examine the water discharge density, water pressure and its effect on cargo fires.[1]

The results of these tests clearly established a relationship between water application rates, fire growth rates and heat release rates. Importantly the research suggests that there are critical water application rates below which the FFFS has virtually no effect.[2]

Interestingly discharge densities of 15mm/min provided immediate fire suppression, 10mm/min fire suppression and 5mm/min fire control. This relationship was also influenced by operating pressure – the higher the pressure the better the performance. Mist systems were also investigated and as a general rule were found less effective than the same application rate in a sprinkler system. See Figure 1. Neither system was effective against shielded fires. [2]

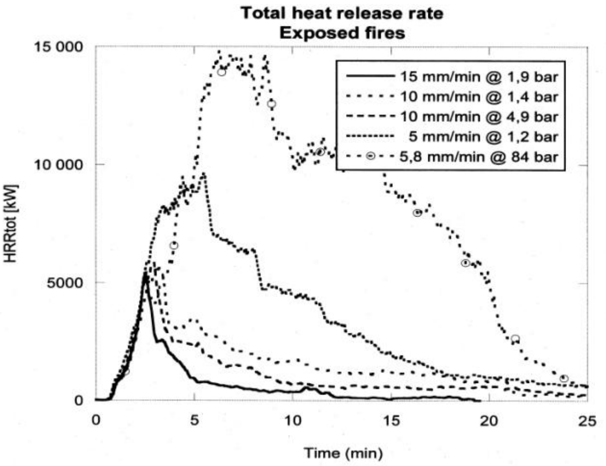


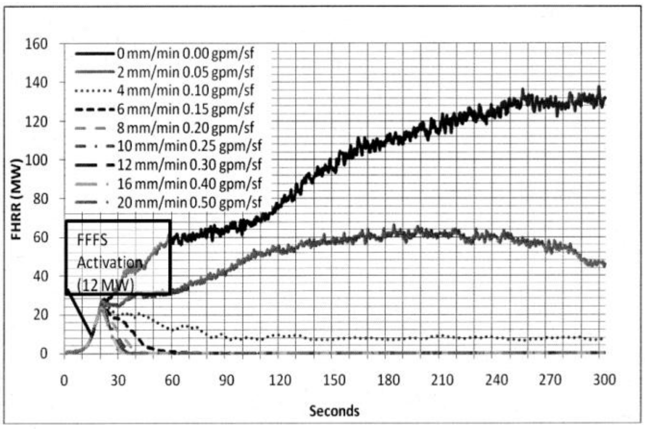
Figure 1: Total heat release rate histories for the fire tests using various water application rates and pressures without shielding. (Arvidson 2010 [2])

However water mist systems are generally regarded as a viable alternative to sprinklers because they are able to achieve good attenuation of heat radiation and cooling although they have reduced fire suppression performance. Mist systems require early activation to minimise fire growth and reduce peak heat release rates. [3,4,5]

Computational analysis using CFD has recently been undertaken for varying FFFS water application rates.[6] The results of this analysis suggest that for an unshielded fire there is a critical water application rate under which fire growth is not significantly reduced. In this CFD analysis the authors suggest it is around 4mm/min, however review of their CFD results suggests it may be higher (perhaps around 6mm/min). Like the scaled experiment results (above) shielded fires perform poorly no matter what the application rates although in all instances fire spread is controlled.

A summary of predicted heat release rates with varying water application rates is found in Figure 2.

Figure 2: Predicted CFD Fire Heat Release Rate for Varying Water Application Rates-Unshielded Fires (Harris 2010 [6])



This scale model and CFD experimental data is compared with the actual experience in the Burnley tunnel fire in the first section of this paper. In short it is consistent with the experience from Japan and Australia about the effectiveness of their deluge systems at fire fighting application rates of in the order of 10mm/min. The role of droplet size distribution in this performance warrants further investigation.

2.2. Shielded Fire Growth

All recent analysis suggests that FFFS has minimal impact on shielded fires. [6, 7]

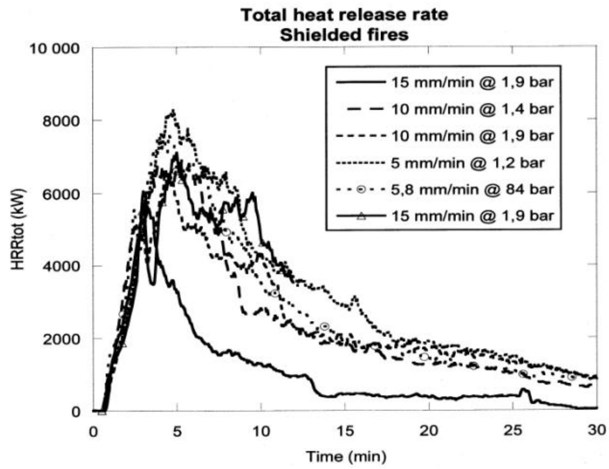


Figure 3: Total heat release rate for shielded fires in full scale test (Arvidson 2010 [2])

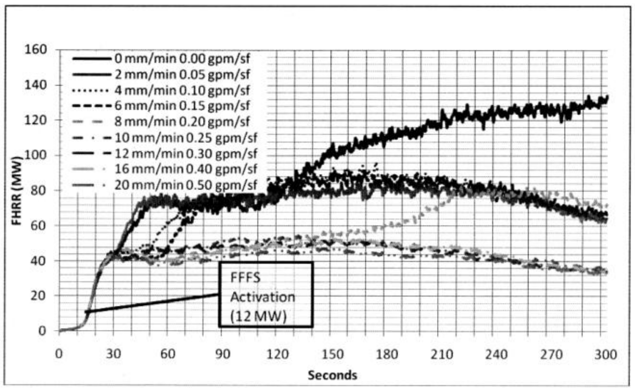


Figure 4: Fire heat release rate for shielded tests using CFD analysis (Harris 2010 [6])

These results are consistent with earlier concerns by NFPA502 and PIARC that FFFS does not put out fires within vehicles. However in all instances fire spread is predicted to be substantially reduced despite the fire not being constrained when shielded. Furthermore the effects of FFFS activation upstream of an event and the migration of droplets horizontally beneath a shield have not yet been modelled in detail.

In practice multiple FFFS zones are operated in a real tunnel and the horizontal migration of water droplets under the effect of longitudinal ventilation may be the reason for enhanced FFFS performance even in shielded situations. This should be the subject of further research. The effects of FFFS in this regard are noted in the examination of the Burnley event in this paper. Fires were not extinguished by the FFFS in shielded environments nor in the Burnley fires.

One of the largest effects of FFFS is the reduction in radiated energy levels and the substantial reduction in the risk of flashover.

3. THE IMPACT OF FFFS ON TUNNEL VENTILATION

3.1. Backlayering

Increased interest in FFFS has rightly raised questions with respect to the management of backlayering during FFFS activation in an emergency. There has been literature on the phenomenon without FFFS but little or no published data with FFFS use.[8] Experimental data is now emerging which confirms that the control of backlayering is not an issue with FFFS activation. The longitudinal airflow is able to maintain backlayering because the FFFS reduced the smoke temperature thereby reducing the driving force propagating the smoke which reduces the amount of ventilation required to prevent backlayering.[7]

Although this is a theoretical study (based on a scale model) and does not take into full regard the effects of destratification it nonetheless is consistent with the experience from Japan and Australia that preventing backlayering is not an issue in tunnels with FFFS.

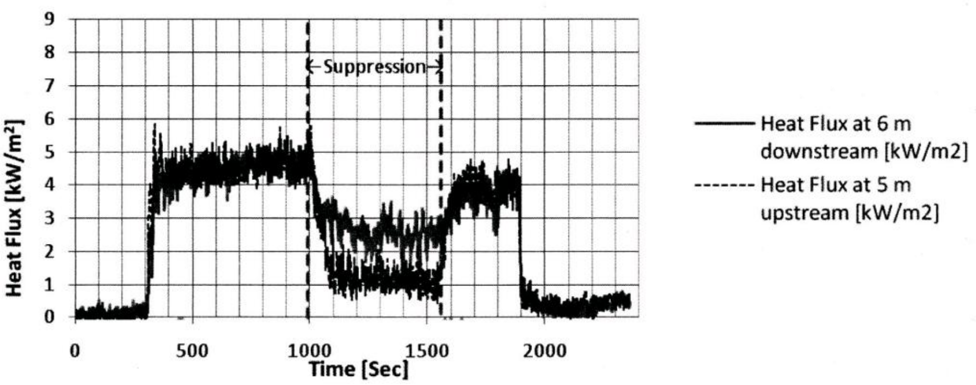


Figure 3: A comparison of heat fluxes measured 5m downstream and 6m upstream over time (Yoon J. Ko and George Hadjisophocleous 2010 [7])

The reduction in heat flux is thought to reduce the amount of energy required to stop backlayering.

3.2. Longitudinal Airflow

With a theoretical reduction in fire growth rates and heat release rates as a result of FFFS use it also follows that achieving critical airflow velocities remains a high priority in FFFS equipped tunnels. Indeed this is required in order to achieve both control of backlayering and not to increase the fire size by virtue of unnecessarily large longitudinal velocities.

It is already well established that increases in longitudinal ventilation velocity can increase heat release rates significantly. [9, 10, 11, 12]

Balancing the need to control backlayering with the undesirable acceleration of fire growth remains a high priority in real tunnels.

The most recent research suggests that the rate of burning of charring fuels (such as wood and thermo setting plastics) exhibits a clear dependence on ventilation velocity while pool fires are less sensitive to such changes. [13]

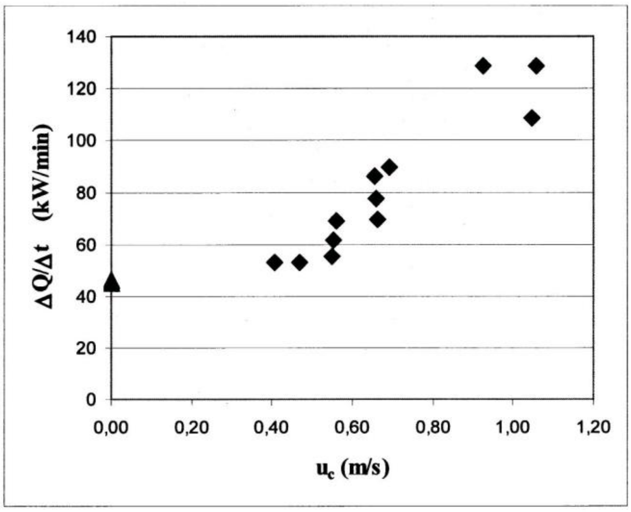


Figure 4: The fire growth rate as a function of the longitudinal ventilation velocity [13, 14]

It is conceivable that early tests which relied upon pool fires for the test methodology would have failed to detect this phenomenon. Furthermore even where tests were conducted using non-charring fuels (the majority of synthetic polymers) they would have behaved like a pool fire. This may be an explanation for why such phenomenon has been poorly understood. The consequences of this are likely to have adversely impacted the size of fires in tunnels because of insistence by operators in operating high longitudinal velocities during emergency mode despite pleas from Fire Brigades to do otherwise. [15]

The positive impact of this phenomenon was revealed in the Burnley fire event where longitudinal velocities were rapidly reduced following the outbreak of fire and backlayering controlled while the FFFS concurrently operated successfully.

4. BURNLEY TUNNEL FIRE - MARCH 2007

The Burnley tunnel is a single direction, 3 lane tunnel of 2.9km length. It has a traffic flow of around 100,000 vehicles per day.

On 23 March 2007, at 09:52:30 am a truck travelling eastbound made an unscheduled stop in Melbourne's CityLink Burnley tunnel. Over the next two minutes 103 vehicles passed the stopped truck without incident. Two minutes later, by 09:54:24 seconds several vehicles, including 4 HGVs and 7 light vehicles had crashed, 3 people were dead and fire and a series of explosions were initiated.

By 09:56:00am (two minutes after ignition) emergency ventilation and a fixed fire suppression system had been activated.

The following eye witness evidence from the criminal court case against the driver graphically illustrates the sequence of events:

- *---Essentially I heard the screeching of tyres. I looked in the rear vision mirror; saw the car careering into the back of the truck. The nose of the car went down, the car lifted up like that so - and then there was another smash from behind by a truck.*
- *---I saw the truck hit it and the - I can only assume that it was the gas tank of the vehicle that exploded.*

- *---I saw the explosion.*
- *---Well I continued to drive through the tunnel. There were - there was another explosion shortly after that which was a much bigger explosion. I remember the windows of my car vibrating as a result. There was also another announcement that came over the speaker saying that there had now been an incident in the tunnel and that vehicles were to slow down to 60 kilometres an hour… "*

This evidence graphically describes the crash, fires and subsequent explosions. The initiating events for this incident were large – large in the context of prior catastrophic events such as the engine compartment fire at Mont Blanc. Yet, despite the severity of these initiating events the fires were contained, with no flash over or other significant fire growth occurring once the deluge fixed fire fighting system was initiated.

However, it was not merely the presence of the fixed fire fighting system which was critical – it was that the ventilation system was effective in that it stopped backlayering (up a steep tunnel grade of 6%) and reduced the longitudinal airflow rapidly (to approximately 2m/sec) in order to optimize smoke extraction and minimize ventilation induced fire growth. It was the fire brigade that put the fires out – the deluge system merely kept the fires small enough to allow effective emergency services intervention.

Following is a summary of key events for the 2007 Burnley Tunnel Fires as given in evidence in the Supreme Court Proceedings DIRECTOR OF PUBLIC PROSECUTIONS v. DAVID LAWRENCE KALWIG 16/07/2009 [This evidence is indicative only of the events – the currently suppressed Technical Report for the Coroner (Dix 2008)] contains detailed technical information on the events):

- *"At 9:52:30 a truck stopped in the left (slow) of three lanes in the east bound Burnley Tunnel.*
- *Between 9:54:26 and 9:54:30 a series of collisions, explosions and fires occur when a truck crashes into several cars and HGVs in the region immediately behind the stopped truck. Eventually the truck which initiated the series of crashes hit the stopped truck and pushing it many metres forward.*
- *At 9:55:37 the tunnel operator enabled emergency mode in preparation for the smoke extraction, deluge operation and evacuation.*
- *At 9:55:50 the emergency response plan was initiated by the tunnel controller including activation of emergency smoke extraction and the deluge system.*
- *At 9:55:54 the smoke extraction system was activated.*
- *At 9:56 the fixed fire suppression (Deluge) was activated."*

Three people were killed in three different vehicles. Two of the three deaths were determined to be "effects of fire". The fires which killed these people were not, and could not, be extinguished by the deluge system as expected from the experimental results. [2, 6] All those killed suffered fatal serious physical injuries in the car crashes.

The lack of demand to the outsides of the vehicles involved in the fires, and the lack of fire spread by flashover is also to be expected from theoretical observations. [16]

The incident resulted in several hundred people being evacuated from the tunnel – and their vehicles. None of the evacuees or their vehicles was injured or damaged. The tunnel only suffered minor damage, and could have been re-opened 10's of hours later if the extent of the damage could have been more rapidly determined.

Mont Blanc Tunnel after fire (no suppression system.)

Burnley Tunnel after fire - road surface and tunnel walls and services still intact.

4.1. Discussion

In the Burnley incident the ventilation system rapidly reduced the longitudinal velocity to approximately 2m/sec. This low ventilation rate was sufficient to stop backlayering despite the buoyancy effect caused by the tunnels steep grade of in excess of 6.2% at the incident location.

The rapid activation of the FFFS and the comparatively low longitudinal velocities coincided with only minimal fire growth following the crash, explosions and subsequent fire.

This is entirely consistent with the theoretical results noted in this report.

The fire inside the structure of the prime mover was not extinguished by the FFFS but by the intervention of fire fighters. This is entirely consistent with the expectations derived from experiments involving shielded fires.

The absence of flashover and lack of accelerated fire growth is consistent with the experimental data on the effects of a FFFS with water application rates roughly in the order of 10mm/min.

5. CONCLUSIONS

The rapid and accurate use of Burnley's FFFS coupled with effective longitudinal air velocity control coincided with minimal tunnel damage, no non crash human victim fire related injuries and rapid reopening of the infrastructure.

There is now growing theoretical research which supports the view taken in Australia and in Japan that the use of FFFS coupled with advanced tunnel ventilation control, rapid incident detection and accurate response positively contributes to tunnel fire safety and asset protection. The differences in the performance of FFFS systems as a function of droplet size distribution warrants further analysis in the tunnel fires context.

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