Advisory Committee on Tunnel Air Quality

TP05: Road Tunnel Stack Emissions

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Summary

- Road tunnel ventilation stacks work by exploiting the turbulent mixing in the atmosphere to efficiently disperse air pollutants. This point has been recognised by air quality scientists and air pollution engineers for decades, and has led to the widespread adoption of the stack as a means of reducing the impacts of pollutant emissions.
- Due to the long history of stacks being used to disperse industrial air pollution, there are numerous validated and extensively used atmospheric dispersion models to predict stack impacts. These models are used by regulatory agencies and research communities. These communities look to improve these models over time.
- Experience from previous motorway tunnel projects, both in Sydney and in other areas of the world, has demonstrated that air dispersion modelling for tunnel stacks is robust and conservative, and that tunnel ventilation stack emissions do not measurably affect local or regional air quality.

1. Scope

Polluted air in tunnels can either be vented from elevated outlets (ie stacks) and/or at ground level from the tunnel portals. This paper (Technical Paper 5) considers stack emissions, whereas Technical Paper 6 covers portal emissions.

2. Why and when stacks are used

Many road tunnels vent exhaust air to the atmosphere at the exit portals (see Technical Paper 6 – Road Tunnel Portal Emissions, page 2). However, in busier or longer tunnels (typically those longer than 2km) emissions can build up to levels where in-tunnel air quality exceeds acceptable limits. In such cases, ventilation stacks have often been used to increase the throughput of fresh air, effectively increasing the allowable vehicle capacity.

Stacks have sometimes been used where tunnel portals are located in urban and/or residential areas, especially where ambient air quality is already poor. In this case, fans can direct most of the tunnel air out of a separate ventilation stack at an elevated height rather than out of the portals at ground level. In Australia some tunnels have been designed so that all the tunnel air is removed via the stacks, thus ensuring zero exhaust emissions at the tunnel portals (eg Sydney's M5 East, Cross City and Lane Cove tunnels).

Stacks can be deliberately sited away from dense residential areas to address community concern about the impact of the stack. For example, the M5 East stack is located approximately 1km from the tunnel tubes. However, the remote location of stacks considerably increases the construction, maintenance and running costs of a tunnel for no significant gain in air quality, and such designs are very rare outside Australia.

It is common for a road tunnel to have two stacks, one at either end, especially where the tunnel consists of two tubes carrying traffic in opposite directions (each tube has one stack). Although a tunnel with two stacks (one for each tube) may seem more expensive than a single bi-directional tunnel with one stack, the additional construction cost is more than compensated for by the reduced cost of pumping air around the system to the single stack, or the cost of a separated ventilation duct, as in the case of the Cross City tunnel. The second stack also provides a partial back-up ventilation option in the case of one stack being non-operational (although this requires extra ducting).

Since the 1990s there has been a substantial reduction in exhaust emissions per vehicle due to technological improvements (see Technical Paper 1 – *Trends in motor vehicles and their emissions* for more details). This means that tunnels can now generally be longer, or have a lower ventilation requirement, than in the past before in-tunnel concentration limits are approached. Consequently, the operation of ventilation stacks in some existing tunnels is being reduced, or the stacks are only being operated during the most polluted conditions (such as in Sydney's Eastern Distributor tunnel). Moreover, stacks are being removed from some new designs (eg Hafnerburg Tunnel, Switzerland) without compromising air quality. Continuing technological developments mean that the downward trend in vehicle exhaust emissions is likely to continue for some time to come. However, in the case of particulate matter (refer Technical Paper 1 - *Trends in motor vehicles and their emissions* for an overview of traffic related air pollutants) it should also be noted that as exhaust emissions decrease, non-exhaust emissions (such as those from brake and tyre wear) will become relatively more important.

3. What do stacks achieve?

Stacks work by taking advantage of the turbulent mixing in the atmosphere to efficiently disperse pollutants, and the fact that wind speed generally increases with height. This has been recognised for decades by air quality scientists and air pollution engineers, and has led to the widespread adoption of the stack as a means of reducing the impacts of emissions in populated areas. Concentrations of pollutants at ground level are progressively reduced as the height of the stack increases. For example, Hibberd (2006) calculated that the impact at ground level of emissions from the 35m stack of the M5 East tunnel was 1/50th of that from the equivalent emissions from a portal.

Computer and wind tunnel modelling, as well as observational studies, suggest that the greatest impacts from a stack occur some distance from the stack (eg 600 – 1,200m in the case of the M5 East (Hibberd, 2003)). The greatest impact is also largely restricted to directions which are downwind of the stack in the most frequent local wind directions, and there may be effectively zero impact in many directions. This effect can be exploited to select stack locations which direct peak concentrations away from sensitive receptors. However, stacks are designed so that even these peak concentrations do not lead to any significant or measurable impact on the local community, as predicted by modelling and frequently confirmed by monitoring.

4. Predicting and assessing stack impacts

The use of stacks for dispersing air pollution has a long history – dating back to the industrial revolution. Consequently, numerous validated atmospheric dispersion models are available (and used) for predicting the impacts of stacks. These models perform well in predicting the dispersion of air pollutants, especially in locations with flat or simple terrain. In areas where the terrain is more complicated (eg valleys and ridges) model predictions can be more uncertain. In these situations, the model uncertainty is generally compensated for by modelling conservative scenarios (eg worst case and/or applying safety factors). Uncertainty in dispersion modelling may arise if tall or large buildings are close to the stack. This uncertainty is generally managed by carefully selecting a model that best handles the local challenges, using conservative assumptions or safety factors in the modelling, or avoiding such locations if possible.

In general, there is a 'diminishing returns' relationship between stack height and ground impact, with increases in stack height leading to progressively smaller reductions in ground level concentrations.

The accuracy of dispersion modelling for road tunnel stacks hinges on accurate estimates of traffic flow, traffic composition, traffic speed, vehicle emission factors, ventilation system operating parameters, and the stack exhaust temperature (which influences how buoyant the emissions are), all of which are difficult to specify before a tunnel opens.

It is common practice to assess stack impacts with respect to ambient air quality standards and guidelines, such as the the National Environment Protection Measure for Ambient Air Quality (AAQ NEPM), or international equivalents, and WHO Guidelines.

5. Monitoring stack impacts

Post-construction monitoring programs for road tunnel stack impacts are not common internationally. However, observational studies or monitoring programs have been established in the case of some road tunnel projects in NSW, as a condition of the planning approval issued by the Minister for Planning, to validate model predictions and to provide the community with reassurance regarding a stack's effectiveness.

Where monitoring is undertaken this can include the continuous measurement of key air pollutants over months to years. It can also include screening-style passive sampling campaigns, in which low-cost samplers provide an average concentration of a given pollutant over a week to a month.

Five continuous ambient air quality monitoring sites were installed around the M5 East tunnel, four at the Cross City tunnel and six around the Lane Cove tunnel in Sydney, as well as two each (one for each stack) at the CityLink and EastLink tunnels in Melbourne. Analysis of monitoring data for the M5 East tunnel concluded that the impact of the stack was too small to be detected, that air quality in the area had experienced no significant change, and therefore that the impact of the stack on the community was negligible (Barnett et al., 2003). Data from the monitoring confirmed the pre-construction modelling to be weakly conservative (Beyers et al., 2003).

For a given pollutant the use of multiple ambient air quality monitors at different locations in the vicinity of a stack allows the impact of the stack to be distinguished from other influences. For instance, the use of five ambient air quality monitoring sites within the vicinity of the M5 East tunnel stack made it possible to determine that occasional high pollution values, especially those for PM_{10}, were related to background sources (predominantly bushfires) and were not associated with the M5 East tunnel itself (Barnett et al., 2003).

Monitoring at four sites near the Cross City tunnel stack was conducted for one year at two elevated sites and for three years at two ground-level sites. The monitoring data are available on the tunnel website (**www.crosscity.com.au**). Monitoring at four ground-level and two elevated sites around the Lane Cove tunnel (two plus one near each stack respectively) was conducted between April 2005 and March 2010 (the elevated stations closed in April 2008). The monitoring data and periodic audit reports are available on the tunnel website (**www.lanecovemotorways.com.au**).

Monitoring at Melbourne's CityLink tunnels has found that levels of the traffic-related pollutants carbon monoxide and nitrogen dioxide were similar to those observed elsewhere in the EPA Victoria network, and well within air quality objectives. No impact of the emissions from the CityLink project on local air quality has been detected (EPA Victoria, 2002, 2003, 2004).

Screening-style passive sampling campaigns were conducted before and after tunnel opening as part of the Lane Cove Tunnel Air Quality and Respiratory Health Study (Woolcock, 2006). This study reported between a 0.3 and 7.0 parts per billion (ppb) reduction in nitrogen dioxide concentrations between the pre-tunnel and post-tunnel campaigns around the area of the stack. Analysis of the continuous monitoring data for the same study found that, after accounting for changes in regional air quality, the elevated sites near the ventilation stacks recorded significant decreases in particulate matter, oxides of nitrogen and nitrogen dioxide in the year after the tunnel opened (Cowie et al., 2012).

In combination these Australian road tunnels, and those in Sydney in particular, represent probably the largest database of tunnel-related air quality monitoring in the world. Although the data is largely publicly available it has not previously been collated and summarised. It is recommended that the data is analysed and disseminated to make it more easily accessible to the public.

6. Further information

For further information related to this topic please see:

Technical Paper 1	*Trends in motor vehicles and their emissions*
Technical Paper 4	*Road tunnel ventilation systems*
Technical Paper 6	*Road tunnel portal emissions*
Technical Paper 7	*Options for reducing in-service vehicle emissions*
Technical Paper 8	*Options for treating road tunnel emissions*
Technical Paper 11	*Criteria for in-tunnel and ambient air quality*

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