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# On the problem of ventilation control in case of a tunnel fire event

Peter Sturm*, Michael Beyer, Mehdi Rafiei

*Graz University of Technology, Austria*

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ABSTRACT

The proper operation of a ventilation system plays a key role in tunnel safety. Foremost, the ventilation system needs to provide acceptable air quality for the safe passage of tunnel users. Further, it needs to provide tenable environment and to facilitate rescue conditions during a smoke or fire event. While accomplishing the first task (normal operation), i.e. providing sufficient fresh air, is relatively straightforward, dealing with the second issue is the subject of considerable debate since defining the best means to ventilate a tunnel during a fire emergency is not always clear.

Although fire tests in tunnels have been performed since the early 1960s, and although the topic of fire ventilation was raised in early national and international guidelines, relatively little interest was given to fire ventilation until several big fire events occurred in the 1990s. The tunnel ventilation systems and ventilation methodologies existing at that time proved to work well under normal operation, but failed during fire ventilation. Nowadays, the design and operation of the ventilation system during fire incidents (commonly called 'fire ventilation') is a major topic. While the design might follow the well-established principles, the question, 'how to control tunnel ventilation during a fire event?', is quite controversial. This paper discusses methods of fire ventilation with a focus on the methodologies themselves as well as on the requirements for sensors and control technologies.



## 1. Background

The issue of fire and smoke control is presented in various publications (e.g. [1–4]). These publications address the threats to human health due to fire events, e.g. high temperatures, the existence of various toxic gases, and low oxygen content. While low visibility poses risk to evacuation as well as the ability to rescue and firefighting, high temperatures and high radiation heat also result in a spread of the fire as it happened in the Mt. Blanc and the Tauern tunnel fire incidents in 1999 [3]. Hence fire and smoke control is essential to:

- save lives by facilitating user evacuation,
- support rescue and fire-fighting operations,
- reduce risk of explosions,
- reduce damage to tunnel structure and equipment and to surrounding facilities [2].

* Corresponding author. Fax +43 316 873 30202.
*E-mail address:* sturm@ivt.tugraz.at (P. Sturm).

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The fire and its influences to the tunnel environment must be controlled, typically by tunnel ventilation. Different countries have different philosophies regarding fire ventilation. While some prefer to focus on preventing backlayering, that is, the movement of smoke upstream of the fire, others opt for maintaining low tunnel air velocities to reduce smoke propagation rates, at least during the self-evacuation phase. This is somewhat controversial as the first option requires relatively high velocities upstream of the fire (2.5–3 m/s), while the latter requires relatively low smoke propagation velocities as the walking speed within a smoke-filled zone is about 0.5 m/s [2]. Hence, in practice, a compromise is often made by applying a low velocity in the range of 1.0–1.5 m/s upstream of the fire. This minimises backlayering effects of the smoke on the upstream side and maintains lower smoke propagation downstream of the fire.

Another important consideration is the ventilation system itself. While in tunnels using longitudinal ventilation smoke usually is transported from the fire site downstream the whole tunnel, modified transverse ventilation systems allow for a local smoke extraction inside the tunnel and hence for a smoke-free zone over large areas of the tunnel to both sides of the fire. However, transversely ventilated tunnels need to have a complex ventilation control system in order to confine smoke to the extraction locations [13].

It is of vital importance to have correct information about air/smoke movement within the tunnel recognizing the importance of controlled operation of transverse ventilation. Monitoring of air/smoke movement strongly depends on correct air/smoke velocity readings, i.e. on reliability of the sensors and on their location inside the tunnel.

Directive 2004/54/EC [5] defines minimum safety requirements for road tunnels within the Trans European Road Network (TERN). The directive covers the need for ventilation as well as the requirements for equipment. Although explicitly valid only for the TERN road network, it nevertheless represents the state of the art for application in many tunnels within Europe and throughout the world. However, the Directive defines requirements for technical installations only and does not cover questions of emergency operation. The relevant information in such cases can be found in international documents (e.g. [2–4]) or various national guidelines (e.g. [6–8]).

## 2. Ventilation systems and philosophy of ventilation during a fire

In the context of this article ventilation during a fire incident including smoke production will be called fire ventilation. During fire ventilation, smoke management is ideally achieved by dilution and removal of smoke. Smoke filled air has to be replaced by clean or smoke-free air, which is either supplied mechanically or drawn in through the portals. Dilution can improve tenability e.g. by reducing concentrations of toxic gases. The basic principles of smoke movement have already been described in detail in Ref. [3] and those of smoke control in Ref. [4]. These principles are still valid, yet PIARC publications only provide guidance. More detailed and binding instructions are mostly given in national guidelines. However, whatever the guidelines state, one must always be aware that fire ventilation is only one part of tunnel safety, and that it is subject to several constraints in the form of design criteria (e.g. fire load) and operation possibilities [10].

### *2.1. Longitudinal ventilation*

#### *2.1.1. Ventilation philosophy*

The philosophy for fire ventilation in longitudinally ventilated tunnels is quite simple. Polluted air is discharged via portals or ventilation shafts. The main consideration is the air velocity that is generated and the sequence of fan activation. Concerning the air/smoke velocity, there is controversy regarding the preference of ‘critical velocity’ or ‘low velocity’.

A *critical velocity* philosophy is applied in order to avoid backlayering, i.e. to prevent any upstream movement of smoke along the tunnel. Typical values for critical velocity are in the range of 2.2–3.5 m/s for fire sizes around 30–50 MW heat release rate. However, with a heat release rate of 30 MW the downstream air velocity will increase by a factor of 2–3 compared to the velocity upstream of the fire location. This results in smoke propagation velocities much too high to allow for self-rescue downstream of the fire. Hence, such a ventilation philosophy can only be recommended for tunnels with unidirectional traffic where traffic downstream of the fire has the possibility to exit the tunnel (i.e. tunnels with low congestion levels).

A *low velocity* philosophy is recommended by PIARC [4], as well as in many national ventilation guidelines (e.g. [6–8]) for bi-directional tunnels and for tunnels with unidirectional traffic where the specific conditions prevailing at the site of the incident (e.g. fire within traffic congestion) remain unclear. Here, target velocities of the upstream (i.e. cold) air are in the range of 1.0–1.5 m/s. Such air/smoke velocities are a compromise between ‘accepting some backlayering’ and ‘moderate air/smoke velocities downstream the fire’. As the traffic conditions near the fire are in most cases not known, this ventilation philosophy the most appropriate is in many cases. However, it requires control of air velocity inside the tunnel and hence the appropriate control equipment.

A *near zero velocity* philosophy should not be applied, as the local concentrations of toxic gases as well as the local temperature will increase strongly and will reduce the tenability near the fire zone dramatically. In addition, any change in tunnel conditions such as heat release rate, outside wind pressure, etc. result in unpredictable smoke movement inside the tunnel, particularly near the fire. Self-rescue, supported rescue, and fire-fighting efforts are significantly impacted. Thus PIARC [4] classifies such a ventilation philosophy as being ‘less favourable’. In fact such a ventilation strategy is very risky and should be avoided whenever possible.

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