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Simulation of smoke from a burning vehicle and pollution levels caused by traffic jam in a road tunnel

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Abstract

Detailed analyses of smoke movement from a burning vehicle in a road tunnel have been carried out for the westbound Melbourne City Link tunnel. The time-averaged equations for velocity, pressure, temperature, and mass fraction of emissions were solved for transient condition using the CFD software FLUENT 6.0. For the analysis, a burning bus was assumed to release an equivalent energy of burning 500 l of diesel in 6 min, with vehicles upstream of the fire at a standstill. On the other hand, the vehicles downstream of the fire had enough time to escape from the tunnel through the exit portal. Due to the action of jet fans, most of the smoke was pushed downstream of the fire. The smoke had also dispersed about 55 m upstream of the fire, putting the passengers in this region at great risk. The emissions released from the vehicles in the jam, with their engines running, also posed a threat to human health. Within 8 min after the fire had started, the mass concentrations of O_2, CO_2 and CO were in the ranges of 0.12–0.15, 0.08–0.11 and 0.0006–0.0014, respectively. Therefore, quick evacuation of the passengers is essential in the event of a fire in the tunnel.

Keywords: Tunnel; Fire; Smoke; Traffic jam; Pollution

1. Introduction

Ventilation of tunnels is necessary to remove pollutants emitted by vehicles and to control smoke in the event of fire. In short tunnels, the airflow induced by the moving vehicles (piston effect) is usually sufficient to drive fresh air in and push polluted air out of the tunnel (Cooley and Turkey, 1965; Goosens et al., 1994; McCormick, 1994; Rosenhead, 1963; Naser and Murad, 2002). In long tunnels, however, mechanical ventilation systems, such as jet fans and exhaust shafts, are essential in addition to the piston effect to augment the airflow inside the tunnel to keep the levels of toxic gases within safety limits (Cooley and Turkey, 1965; McCormick, 1994; Casale et al., 1996; Ferro et al., 1991). Assessments of airflow patterns and fires in tunnels, railway platforms and other complex structures have been done by mathematical models using computational fluid dynamics (CFD) techniques (Rhodes, 1996; Rhodes et al., 1991a,b). The predicted velocities and temperatures of these studies were validated mainly by comparing them with room experiments (Kumar and Cox, 1985; Biollay and Chasse, 1996). Studies on how the heat release rates of the fires were affected by the ventilation in tunnels were done by several authors (Carvel et al., 2001; Kunsch, 2002). It was found that forced ventilation had a greater enhancing effect on the heat release rates

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of heavy goods vehicle fires, but had little effect on those of car fires.

Detailed exhaust gas flow and smoke movement patterns inside tunnels are essential for the design of ventilation systems. However, numerical predictions of these in relatively longer tunnels are restricted by computer power and CPU time. Therefore, numerical developments used for the simulation of tunnel ventilation systems and pollution levels are restricted to short tunnels or shorter versions of long tunnels (Naser and Murad, 2002; Casale et al., 1996; Ferro et al., 1991; Chow, 1996). Nevertheless, reduced scale models may not always be used for long and complex systems that integrate many ducts and nodes (Ferro et al., 1991; Jacques, 1991).

Before putting a tunnel into operation, full-scale fire tests in tunnels are carried out for limited cases to assess the smoke removal capacities of their ventilation systems. However, the tests are limited to fires of lower capacity to avoid damaging the tunnel ceiling or the tunnel itself. Fire tests were carried out in two French road tunnels of about 1500 m, burning a car in one tunnel and a lorry in the other (Perard and Brousse, 1996). It was concluded that ventilation inside the tunnel was essential to de-stratify the smoke and push it towards the tunnel mouth. It has also been demonstrated that failure of the ventilation system could lead to the most damaging situation, which could be avoided with the use of smoke removal equipments.

There were cases of fires in tunnels and underground facilities that led to several recommendations to improve the evacuation procedure, ventilation system and warning mechanism for vehicles entering tunnels (Chow and Li, 2001; Fennell, 1988; Kirkland, 2002; Pucher and Pucher, 1999). It was emphasized that vehicle occupants should switch off the engines and run away for evacuation, rather than staying inside the car until firemen reached them. Continuous training given to tunnel management staff on the evacuation procedures is as essential as the understanding of fire dynamics and human behaviour likely to be experienced, so that accurate action guidance can be given to the passengers and drivers.

In this study, CFD techniques were used for the simulation of smoke movement from a burning vehicle inside a 1600 m long tunnel. The tunnel had three lanes and closely resembled the westbound Melbourne City Link one-way tunnel. Numerical predictions of temperature and velocity profiles due to the action of jet fans are also presented. An assessment of pollution levels inside the tunnel due to traffic jam was also done. The results are compared with the data available in the literature. The detailed predictions obtained with CFD models will thus assist in demonstrating system capability in worst-case scenarios in major accidents involving fire in road tunnels.

2. Melbourne City Link tunnel

The Melbourne City Link tunnel comprises the westbound (Domain) tunnel, which is about 1600 m long and the eastbound (Burnley) tunnel, which is about 3500 m long. The traffic is one-directional on three lanes. Traffic enters the Domain tunnel at Olympic Park portal and exits at Grant Street portal. Traffic enters the Burnley tunnel at Grant street portal and exits at Burnley portal. The tunnel is built to reduce traffic congestion in and around the city. A major part of the tunnel design is dedicated to the air ventilation system that extracts the vehicle emissions from the tunnel and expels them to the outside environment in a controlled manner.

The westbound tunnel contains 12 reversible jet fans mounted in a staggered formation on the ceiling. These jet fans are 1.8 m in diameter and have a capacity of handling 80 m^3/s of air. At the western end of the tunnel is a ventilation station, at which polluted air is extracted from the tunnel. The main inlet to this ventilation station is about 200 m west of the tunnel exit portal. Air enters

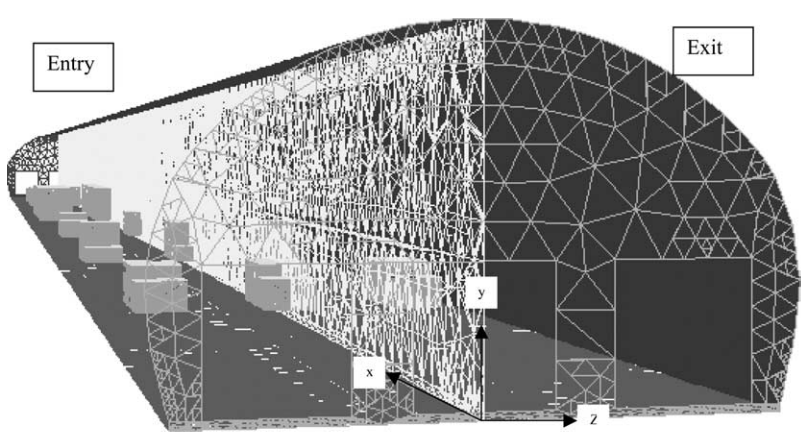

Fig. 1. Solution domain and grid used.