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Critical velocity in ventilated tunnels in the case of fire plumes and densimetric plumes

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Abstract

We focus on the critical velocity in longitudinally ventilated tunnels and on its dependence on the power of the fire source. In particular we aim at identifying the reason for the appearance of the so-called 'super-critical' velocity, a ventilation velocity that becomes independent of the heat release rate as this latter becomes large. A critical review of existing literature studies allows us to point out possible explanations for this peculiar phenomenon. Among these, we focus here on effects related to heat fluxes (diffusive and radiative) and to the presence of large (compared to the tunnel height) flames. To enlighten the role of these phenomena, our approach is that of systematically compare the critical velocities as induced, for a given heat release rate, by densimetric plumes and fire plumes. The study is conducted by combining experimental, numerical and theoretical methods. The experiments were performed in a reduced-scale tunnel using densimetric plumes (air/helium mixture and hot air). Numerical simulations were performed with Fire Dynamics Simulator (FDS) and concerned densimetric plumes and fire plumes (propane). These show that the diffusive heat fluxes at the tunnel walls affect only marginally the critical ventilation.Similar conclusions can be drawn for the role of the radiative fluxes. The results also show that plumes arising from small fires can be reliably modelled as buoyant densimetric plumes released at ground level. In these cases the critical velocity increases with the one-third power of the heat release rate. The flow dynamics (and therefore the critical velocity) induced by larger fires is instead different. Notably, the occurrence of large flames (i.e. larger than the tunnel half-height) represent a source of distributed buoyancy, located downwind of the injection of flammable gases. Their presence induces the critical velocity to become almost independent on the heat release rate.

Keywords: buoyant plumes, critical velocity, fire, tunnel ventilation

1. Introduction

Constraining the propagation of hot smoke with a forced ventilation is a key issue for the management of risks related to the occurrence of fires within road and rail tunnels. This goal can be attained with different ventilation systems, adapted to one-way or two-way tunnels. In the case of a one-way tunnel, the basic strategy is to avoid the propagation of the front of the hot smoke upstream of the fire location, in order to allow the users escaping in the opposite direction and the safety services to approach as close as possible to the fire. To obtain this condition it is necessary to impose a 'longitudinal' ventilation velocity that is referred to as 'critical', and denoted hereafter as V_c. The study of the dependence of the smoke propagation on the power of the fire and on the intensity of the mechanical ventilation has therefore motivated so far a large number of studies. These were performed with a large variety of different experimental approaches, namely

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