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# Experimental study of the effectiveness of a water system in blocking fire-induced smoke and heat in reduced-scale tunnel tests

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ABSTRACT

A water system, consisting of several water mist nozzles, has been installed in a reduced-scale tunnel. Its effectiveness in blocking fire-induced smoke and heat is tested, with and without longitudinal ventilation. A total of 14 fire tests have been carried out, with 250 ml methanol in an iron tray (25 cm × 20 cm) as fuel. Temperatures have been measured by 30 thermocouples, located upstream and downstream of the fire location. The aim is to assess the effectiveness of the water system in preventing smoke spread and in reducing the temperature in the tunnel. Interaction of the water with the fire is avoided. The impact of water pressure, ventilation velocity and nozzle arrangement on the effectiveness in smoke blocking and temperature reduction is discussed. The result confirms that the water system effectively reduces the temperatures and prevents smoke spreading in the absence of longitudinal ventilation. However, strong longitudinal ventilation (0.8 m/s ventilation velocity in the reduced-scale tunnel, corresponding to critical velocity in full-scale (1:10) tunnel) reduces the effectiveness in blocking the smoke spreading by the water system, although the temperature reduction downstream the water system remains in place. Higher water pressure makes the cooling effect stronger, because more and smaller water droplets are injected into the tunnel. For a given level of water pressure level, the impact of the nozzle row configuration is small in the tests.

## 1. Introduction

In recent years, the interest for fire safety issues in tunnels has increased dramatically due to a significant increase in number of tunnels worldwide and due to numerous catastrophic tunnel fires (Carvel and Beard, 2005). As an international agreement (Montreal Protocol) announced that bromine-based chemical agents will phase out worldwide sales (Roberts, 1993), water systems have become an important and interesting field of investigation. A distinction can be made between water mist systems and sprinkler systems, based on the droplet size. In a water mist spray, approximately 90% of the droplets have a diameter of less than 500 μm, which is an order of magnitude smaller than in conventional sprinkler sprays (Grant et al., 2000).

Due to the relatively limited cross-sectional area in tunnels, hot smoke can spread rapidly, e.g., downstream with the traffic flow or due to longitudinal ventilation. Consequently, people downstream of the fire may be exposed to high temperatures and toxic gases, especially in urban tunnels which are likely to clog during rush hours. Inspired by fire compartmentation in buildings, it is worth investigating whether a tunnel can be partitioned by a water system into a fire zone and safety zones. If so, people can move from the fire zone into a safe zone through the water system. Obviously, an essential question is to examine to what extent the fire-induced heat and smoke can be blocked by the water system.

To date, many research studies have been conducted concerning the use of water mist systems in enclosures (Jenft et al., 2014; Kim and Ryou, 2003; Prasad et al., 2002; Yang et al., 2010). Restricting the survey to water mist in tunnel configurations, experimental and numerical approaches are found on the interaction between water mist and fire source (Blanchard et al., 2014; Hart, 2006; Li et al., 2013). Small-scale experiments were carried out by Ingason (2008), Chen et al. (2009), and Li et al. (2013) on the suppression efficiency between water mist characteristics (water flow rate, mean diameter, spray angle, etc.) and tunnel environment (ventilation condition, heat release rate, etc.). Blanchard et al. (2014) investigated the interaction between hot gases and a water mist system in a model tunnel. Concerning numerical studies, also a few papers can be found (Blanchard et al., 2014; Hart, 2006; Nmira et al., 2009). The original idea of these studies is to

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discharge the water mist directly on the fire source, so that the heat release rate can be decreased due to the cooling effect through heat absorption by water droplets.

The aim of the present study, on the other hand, is to study the potential use of water mist as a curtain in order to prevent smoke and heat spreading. In other words, the study is not on fire suppression. On the contrary, as explained below, special care has been taken to make sure that the fire heat release rate is not influenced by water mist system during our tests. The effectiveness of the water mist curtain in preventing smoke spreading and in reducing temperatures is described for a naturally and mechanically ventilated tunnel in the present paper.

The use of water curtains in buildings as a boundary of a fire compartment is not new. A real-scale fire experiment, where a water curtain acted as partition to prevent heat and smoke spread to the adjacent room, was performed by Chow et al. (2011). Also in tunnel configurations, some reduced-scale experiments focused on the prevention of fire spread (Amano et al., 2005; Ingason, 2008). In this paper a total of 14 fire tests are discussed, involving a parametric study on the efficiency of smoke blocking and temperature reduction, including water mist characteristics and the longitudinal ventilation velocity in the tunnel.

## 2. Experimental setup

### 2.1. Tunnel geometry

The reduced-scale tunnel is 18 m long, 1.1 m wide and 0.4 m high (Fig. 1). It consists of non-combustible, 8 mm thick fireproof glass (density 2700 kg/m$^3$, heat conductivity 0.041 W/(m K), specific heat 0.84 kJ/(kg K)). In order to avoid destruction of the tunnel, iron plates (density 7850 kg/m$^3$, heat conductivity 45.8 W/(m K), specific heat 0.46 kJ/(kg K)) replace the fireproof glass of the ceiling and the floor near the location of the fire.

In 7 tests, longitudinal ventilation (with velocity 0.8 m/s, see below) was established by an electrically driven axial fan at the entrance of the tunnel. The test protocol was such that the ventilation system was activated at $t = 20$ s after ignition of the fuel. In order to smoothen the air flow from the fan, a net with small grid size (1 cm × 1 cm) was installed at the outlet of axial fan.

### 2.2. Water system

The water system with 13 nozzles in 5 rows (A–E) is presented in Fig. 2. The left hand side shows a sketch, while the right hand side shows a picture. Nozzles in the same row are connected by a pipe with a valve to control opening or closure of the nozzle rows. Through the use of these valves, different nozzle arrangements can be considered. When 4 nozzles are activated ('2 × 2' in Table 2), rows A and C are open. With 5 nozzles ('2 + 3' in Table 2), rows D and E are open, while rows B and D are used in the tests with 6 nozzles ('2 × 3' in Table 2). All nozzles have been installed 25 mm below the ceiling and the distance between two neighboring rows is 0.3 m, except for row E, which is 0.6 m from row D. A water pump supplies the water for all the nozzles. The maximum total water flow rate is 3.5 m$^3$/h and the maximum pressure is 0.65 MPa. Three pressure gauges have been installed in the water supply pipe adjacent to the water pump and nozzles, respectively. Only the data on pressure gauges near the nozzles are used to control the water supply rate to the nozzles. Two levels of pressure have been applied in the tests, namely 0.3 MPa and 0.5 MPa. In order to assure that the flow rate for each nozzle row is the same, the valves have been adjusted before the tests, keeping the pressure at constant level. The test protocol was such that the water supply is activated at $t = 20$ s after ignition of the fuel in the absence of longitudinal ventilation. In case of longitudinal ventilation, the water supply is activated at $t = 40$ s after fuel ignition (i.e., 20 s after activation of the longitudinal ventilation system).

### 2.3. Instrumentation

Temperatures have been measured with unshielded K-type thermocouples. The accuracy of each thermocouple is ±0.1 °C. Their location is shown in Figs. 1 and 3: thermocouple trees were

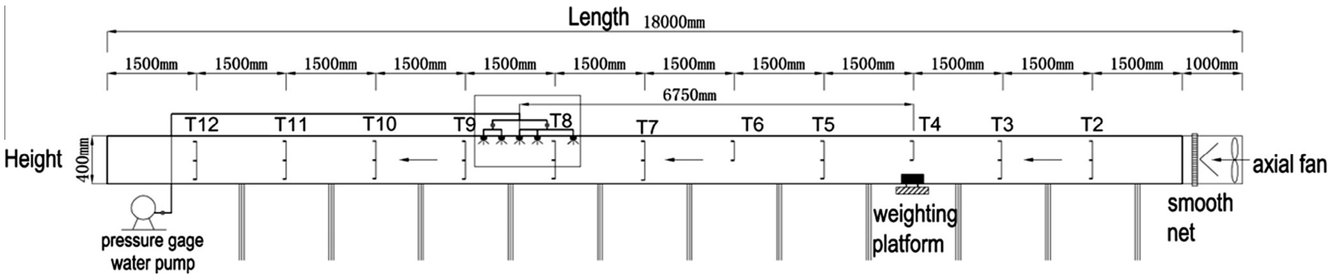

**Fig. 1.** Sketch of the reduced-scale tunnel (side view: vertical section in the mid-plane).

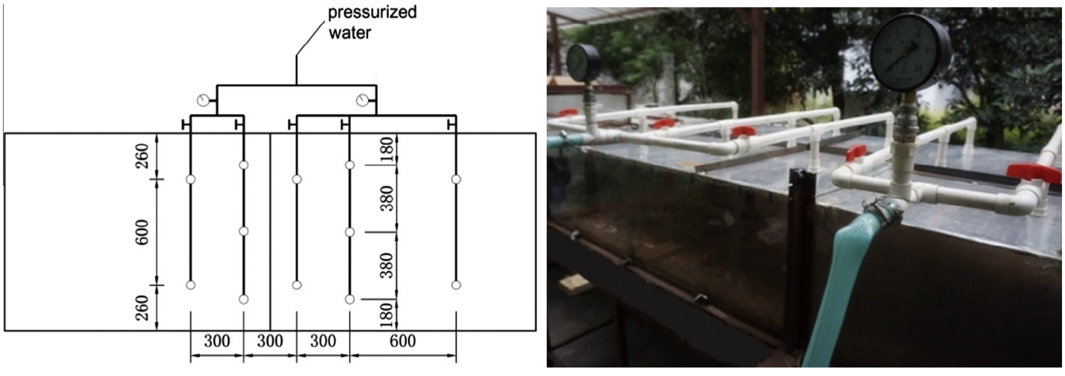

**Fig. 2.** A bird-eye view sketch (left) and a picture (right) of the nozzle system lay-out.