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Model scale tunnel tests with water spray

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Abstract

A model scale study (1:23) was carried out in order to improve the basic understanding of water spray systems in longitudinal tunnel flow. The water spray system consisted of commercially available axial-flow hollow cone nozzles. Tests with both a deluge system made of 12 nozzles placed directly above the fire source and a water curtain system consisting of four nozzles placed either downstream or upstream of the fire source were carried out. A wood crib was used to simulate the fire source, which was designed to correspond to a HGV (heavy goods vehicle) fire load in large scale. A second wood crib was used as a target pile and was placed downstream the ignited wood crib. The parameters varied were the water flow rate and water pressure, the longitudinal ventilation rate and the arrangement of the nozzle system. Possible fire spread between wood cribs, with a free distance corresponding to 15 m in large scale, was investigated.

Keywords: Tunnel; Model scale; Water spray

1. Introduction

The large fires that have occurred in many road tunnels in Europe [1,2] have lead to renewed discussion of the need for a water spray system in order to prevent future catastrophic fires in road tunnels. Also, the Runehamar tests [3,4], which resulted in both rapid and high heat release rates (HRR) using ordinary non-hazardous goods, show that there are good reasons to review many commonly accepted views and attitudes. As a consequence, new innovative water-based technologies are being seriously discussed as a part of the tunnel safety concepts in many new large infrastructure projects. The use of a water spray system (sprinkler, water mist, nozzles, deluge system, hybrid system, foam additives, etc.) in tunnels is, however, still controversial.

The fire spread between large vehicles that have occurred in tunnel fires have placed the focus on the use of water spray systems to prevent fire spread. Systems controlling the fire development or systems cooling the gases through water curtains are often discussed. In the present study, a focus is put on producing well-defined experimental data which can be used for future modelling work. Similar work has been carried out for sprinklers in buildings, e.g. the fundamental work of Kung [5,6] and Tamanini [7] on sprinkler suppression of wood cribs and Rasbash et al. [8] and recently Heskestad on pool fires [9]. An excellent overview of water spray suppression in general has been conducted by both Grant et al. [10] and by Heskestad [11].

There are numerous large-scale tests that have been performed using water spray systems in tunnels [12–21]. The variation in the water discharge density, nozzle types, fuel type and size, ventilation conditions and scale make it nearly impossible to draw any general conclusions about the efficiency of water spray systems and their ability to control or suppress different fires sources. In most of the tests, very little data on test results are given. The test programmes are usually very specific and not designed to allow any general modelling work on the efficiency of the systems.

There is a need for a well-defined test programme focusing on well-instrumented experiments measuring the efficiency of a water spray system. Such data can be used for fundamental modelling work of cooling and suppression theories for tunnel fires. Such information is not presently available. If the measured parameters correlate to each other, one could reduce the number of measurements needed in order to evaluate the efficiency of

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Nomenclature

A the cross-sectional area of the tunnel (m^2)
A_c the total coverage area of the water spray nozzle (m^2)
A_s unit-exposed fuel surface area (m^2)
c the fraction of water applied that fell directly through the shafts of the crib
d droplet diameter (mm)
D the diameter of the probes (m)
E_{extp} the total energy released by the fire during the extinction period (kJ)
E_{tot} the total calorific value (kJ, GJ)
E_w the total energy absorbed due to vaporisation of the spray water flow (kJ)
H_c the effective heat of combustion (MJ/kg)
H_w the latent heat of evaporation of water (kJ/kg)
k a calibration coefficient equal to 1.08
K the k-factor ($l/min\,bar^{1/2}$)
L the probe length (m)
$\dot{m}$ the total air mass flow rate inside the tunnel (kg/s)
$\dot{m}_f$ the fuel mass loss rate (kg/s)
$\dot{m}_{f,a}$ the fuel mass loss rate at activation of water spray system (kg/s)
$\dot{m}_{f,max}$ the maximum freeburning rate of the wood crib (kg/s)
$\dot{m}_w$ the total water application rate (kg/s)
$\dot{m}_{w,c}$ the true water application rate (kg/s)
$\dot{m}''_{w,cr}$ the amount of water needed to extinguish the crib per unit exposed fuel surface ($g/s\,m^2$)
M the mass saved at the end of the water application (kg)
M_a the molecular weight of air (kg/mol)
M_{ash} the mass of the ash after a test (kg)
$M_{cons,freeburn}$ the amount of fuel consumed during the extinction period in a freeburn test (kg)
M_e total water evaporated (kg)
M_{extp} the mass consumed during the extinction period (kg)
M_P the fuel mass consumed before water application (preburn time) (kg)
M_0 the initial dry fuel mass (kg)
N_{spr} the total number of nozzles
P_r the weight fraction of ash
Δp pressure difference for measurements of velocity (Pa)
ΔP the water pressure differential (bar)
$\dot{Q}_a$ the heat release rate at activation of water spray system (kW)
$\dot{Q}_w$ the nominal rate of energy needed to evaporate all water spray flow (kW)
$\dot{Q}_{max}$ the maximum HRR (kW)
$\dot{Q}_{max,freeburn}$ the maximum heat release rate during a freeburn test (kW)
$\dot{q}_w$ the water flow rate (l/min)
$\dot{q}_{w,nom}$ the nominal water flow rate (l/min)
$\dot{q}''_w$ the water flow density (water discharge density) (mm/min)
$\dot{q}_{max}$ the maximum heat flux measured in the longitudinal flow (kW/m^2)
R ratio of crib mass consumed during the extinction period and combustible material remaining at the beginning of water application, Eq. (8)
s_a the spacing distance between the nozzles in direction a (m)
s_b the spacing distance between the nozzles in direction b (m)
T gas temperature (K)
T_a the ambient gas temperature (K)
T_{max} the maximum gas temperature (K)
ΔT_{max} the maximum excess gas temperature (K)
u the average longitudinal velocity upstream the fire (m/s)
u_c the centreline longitudinal velocity (m/s)
u_{nom} the nominal centreline velocity (m/s)
$\dot{V}$ volume flow (m^3/s)
X_{O_2} the volume fractions of oxygen at the measuring station measured by a gas analyser (dry)
X_{CO_2} the volume fractions of oxygen and carbon dioxide at the measuring station measured by a gas analyser (dry)
$X_{i,max}$ the maximum gas concentration (%)
X_{0,O_2} the volume fraction of oxygen in the incoming air (ambient)
X_{0,CO_2} the volume fraction of carbon dioxide measured in the incoming air

Greek symbols

ζ the ratio of mean to maximum velocity
ξ the proportionality coefficient varying depending on type of fuel
ρ_a the ambient air density (kg/m^3)
χ the combustion efficiency
ψ experimentally determined coefficient, Eq. (9)

the system. Further, large-scale tests are expensive and it is difficult to carry out advanced parametric studies at a reasonable cost. Therefore, a model study in a suitable scale is an attractive option. In the present study, model scale tests (1:23) are presented showing in a systematic way the influence of a water spray system on the reduction in HRR, temperatures, gas concentrations and heat fluxes. The analysis of the data focuses on obtaining relative effects of the systems on the situation downstream of the fire source.