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Scaling of wood pallet fires

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ABSTRACT

A method for scaling time-resolved burning behaviors of wood pallet fires has been developed. A series of validation tests was carried out in two different scales and the time-resolved heat release rates were obtained and compared. The results show that the scaling method proposed works very well. The scaling method proposed could be applied to general wood pallets.

1. Introduction

The physical scaling has been widely used in the fire safety science community. Its application permeates nearly every aspect of fire research, from free plumes to fire suppression. Despite the simplification in various applications, the scaling technique has significantly improved our understanding of fire dynamics. Heskestad [1] reviewed scaling techniques, mainly pressure modeling and Froude modeling. These are the two main techniques that have been used. Quintiere [2] also reviewed the scaling applications in fire research with a focus on ceiling jets, burning rate, flame spread and enclosure fires. Ingason [3] carried out numerous studies on fire development in rack-storage fires, both in large scale and model scale. The in-rack conditions were found to scale very well. Perricone et al. [4] investigated the thermal response of a steel tube covered by insulating materials using scaling principles. Relatively good agreements were found but the scaling laws used for the thick insulating materials may not be accurate. Li and Hertzberg [5] conducted a scaling study of heat conduction and heat balance in a room fire. They carried out two series of room fire tests in three different scales where the main aim was to investigate the scaling of temperatures inside the walls. Good agreement between different scales was found.

Scaling of water-based fire suppression systems has also been conducted in open and enclosure fires. Heskestad [6,7] carried out a series of gas and pool fire suppression tests to investigate the credibility of scaling the interaction of water sprays and flames, and obtained a simple correlation for extinguishment of gas and pool fires using water sprays. Quintiere et al.'s work [8] showed that the scaling of suppression of pool and gas fires worked well, although the results in rack-storage sprinkler fires did not show a good correlation. Yu et al. [9,10] tested and investigated the scaling of suppression of gas fires and pool fires using water mist systems and obtained good agreement between model scale and full scale.

In the field of tunnel fire safety, scaling techniques are widely used. The main reason promoting their applications is the high cost of full scale tunnel tests. Note that even in model scales, the ratio of tunnel length to tunnel height should be great enough to scale a realistic tunnel fire. Fortunately the introduction of longitudinal flows allows us to slightly reduce the scaling ratio, compared to an enclosure fire. A large number of model scale tunnel fire tests have been carried out in the past two decades. Bettis et al. [11] carried out nine fire tests using scale models of vehicles in a model tunnel to mimic part of a train used to transport HGVs through the Channel tunnel. Oka and Atkinson [12] carried out a study of critical velocity in a model tunnel. Further, Wu and Bakar [13] carried out tests to investigate the influence of tunnel geometry on the critical velocity. Ingason and Li investigated the key parameters for large fires in model scale tunnels with longitudinal ventilation [14] and with point extraction ventilation [15]. Ingason [16] also carried out a series of 1:10 scale model railcar tunnel fire tests to investigate the effect of openings on the fire sizes. Vauquelin et al. [17] carried out a series of model scale experiments with a helium/nitrogen gas mixture in an isothermal test-rig to investigate the extraction capability and efficiency of a two-point extraction system. Li et al. carried out several series of model scale tunnel fire tests to investigate the critical velocity and backlayering length [18], maximum ceiling gas temperature [19], smoke control in cross-passages [20], and smoke control in rescue stations in long railway tunnels [21]. Lönnermark et al. [22] carried out a 1:3 model scale metro car fire tests in preparation for the full scale fire tests in the Brunsberg tunnel [23]. Model scale tunnel fire tests with water-based fire suppression have also been carried out. Ingason [24] tested performance of a water spray system in tunnel fires with hollow cone nozzles and wood crib

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Nomenclature

a	geometrical parameter for pallet (m)
A_f	total fuel surface area (m^2)
$A_{f,\ ex}$	total exposed fuel surface area (m^2)
$A_{f,\ cont}$	total contact area in a pile (m^2)
$A_{fo,\ cont}$	contact area for one pallet inside a pile (m^2)
b	geometrical parameter for a pallet (m)
c	geometrical parameter for a pallet (m)
d	geometrical parameter for a pallet (m)
E	energy (kJ)
f	parameter in Table 2 (m)
ΔH_c	heat of combustion (kJ/kg)
l	length of a pallet in one direction (m)
L	length scale (m)
L_x	total length of a pile in x direction (m)
L_y	total length of a pile in y direction (m)
L_z	total length of a pile in z direction (m)
m	mass (kg)
$\dot{m}''_f$	mass burning rate (kg/(m^2s))
N	number of pallet layers in a direction
$\dot{Q}$	heat release rate (HRR) (kW)
s	spacing parameter in a wood pallet (m)
t	time (s)
T	temperature (K)
u	velocity (m/s)
V_f	fuel volume (m^3)
V_{fo}	fuel volume of a single pallet (m^3)
$\dot{V}$	fuel volume of a single pallet (m^3)
w_p	total wet perimeter of the fuel in one direction (m)

Greek symbols

ρ_f	fuel density (kg/m^3)

Sup and subscripts

cont	contacted area
ex	exposed area
f	fuel
fo	single pallet fuel
F	full scale
i	symbol for x,y,z
M	model scale
x	x axis (longitudinal)
y	y axis (transverse)
z	z axis (vertical)
*	scaling coefficient

fires. Deluge system and water curtain system were tested. Li and Ingason [25] investigated an automatic water spray system in tunnel fires using full cone nozzles and wood crib fires. Response times for individual sprinklers were modeled using a scaling theory. Li and Ingason [26] also carried out a series of model scale tunnel fire tests with fire suppression systems using wood pallets as fuels. Blanchard et al. [27] carried out one 1:3 model tunnel fire test with six high pressure water mist nozzles and analyzed the gas cooling effect using CFD simulations.

Despite the wide use and experience of the physical scaling, scaling of general solid fuels has not been possible with the exception of the wood crib fires. The main problem is the difficulty in choosing materials that fulfil all the requirements based on the scaling theory. Another problem is that scaling of the pyrolysis process has not yet been well understood. The reason for the exception of wood crib fires is that much work had been carried out on burning rates of wood cribs in 1960s and 1970s when the wood cribs started to become a commonly used solid fire source in experiments [28–30]. A wood crib is a pile of small sticks stacked together with uniform spacing between them. For each wood crib, there are only four geometrical parameters: stick size (rectangular), spacing between sticks, number of layer in the horizontal direction and number of layer in the vertical direction. Research on the burning rates of these small wood cribs provides valuable inputs and facilitated the scaling of wood cribs. Croce [31] and Croce and Xin [32] examined the scaling of wood crib fires and found good agreement between different scales.

Wood pallets are widely used in, e.g., storage and transportation. They have also been used in representation of cellulose fuels in many large scale fire tests, e.g. tunnel fire tests [33–35] and rack storage fire tests [36]. These types of large scale tests mostly involve in tons of fuels and the cost of each test is huge. Sometimes the problem with measurement of the heat release rates using an industrial calorimeter in the lab could even emerge due to the calorimeter capacity and smoke spillage.

A general method to scale these pallets is therefore needed. This would make it possible in future to do large scale tests with wood pallets more cost effectively, without jeopardizing the accuracy of the results to any large extent. This applies especially for scaling of fires without interaction with suppression systems. The motivation for doing this type of research is therefore both economical and scientific. The potential for future use of scaling technique for this type of fuel in different applications is therefore wide.

In the following a method for scaling of wood pallet fires is proposed and validation tests are carried out. The results are analyzed based on a theory developed especially for this type of fuel: wood pallets.

2. Froude scaling

The widely used and well known Froude scaling technique is applied as the basis for the scaling of wood pallet fires. It is impossible and in most cases not necessary to preserve all the terms obtained by scaling theory simultaneously, but the terms that are most important are carefully preserved. For example, the turbulent flows can be scaled well in theory [37]. Despite the fact that the radiation cannot be simply scaled, some previous researches, e.g. [5], showed that the radiation from flames and gases to surroundings was reasonably well preserved between the different scales. This was also supported by Gross's findings [28] that for the wood crib fires the radiative fraction was essentially independent of the fire size. It should however be mentioned that this may not be true if a very small scaling ratio is used, e.g. the radiation fraction from a 50 m diameter pool is lower than a 0.05 m diameter pool. A complete scaling theory can be found in e.g. reference [37]. Scaling correlations for some key variables such as heat release rate, gas temperature and velocity are shown in Table 1.

3. Scaling of wood pallet fires

In the following, a general scaling method for pallet fires is proposed with a focus on the standard European wood pallet fires. The scaling method proposed and the results obtained, however, do not limit to a specific wood pallet. Instead, it could be applied to other similar types of fires.

3.1. Geometric parameters for a wood pallet pile

A standard European pallet (EUR pallet) consists of three layers of wood slabs and 9 wood blocks in the vertical direction, see Fig. 1. The

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