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Experimental and numerical study of low frequency oscillatory behaviour of a large-scale hydrocarbon pool fire in a mechanically ventilated compartment

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ABSTRACT

The contribution presents an experimental and numerical study of the oscillatory behaviour of a pool fire in a confined and mechanically ventilated enclosure. The fire safety issue concerns the loss of dynamic confinement of the enclosure due to large pressure variations and therefore the possible release of toxic products outside the compartment. The experimental analysis is based on large fire tests showing a periodic low frequency oscillatory behaviour of the burning rate. The frequency is 0.005–0.007 Hz (period of 150–200 s) with amplitude of about twice the mean level of the burning rate. A parametric analysis is performed to identify the most influential parameters. This oscillatory phenomenon is explained as a coupling process between the burning rate, the room pressure, the ventilation flowrate, the oxygen concentration and then a feedback effect on the burning rate. The phenomenon occurs for under-ventilated conditions for which the burning region moves within the room leading to the displacement of the flame. Numerical simulations with the fire field model ISIS is performed to check the ability of a standard CFD modelling to reproduce the flame oscillatory behaviour and to give perspective issues for numerical developments. The average values of fuel mass loss rate, compartment pressure, ventilation flow rate, oxygen concentrations and gas temperatures are well predicted. The oscillatory behaviour of the fuel mass loss rate is also obtained with a dominant low frequency although the amplitude of the fluctuations is underestimated due to a poor simulation of the flame displacement inside the compartment. The simulations points out the key effect of the pyrolysis model, the combustion model, the treatment of local extinction and the effect the ventilation flow rate.

1. Introduction

Forced ventilated compartment fire scenarios remain a key issue for safety assessment in nuclear installations. Compartmenting areas confines the fire scene and the set of mechanical ventilation ensures dynamic confinement that enables release of radioactive material outside the installation to be avoided. One difficulty when performing a fire risk assessment of these configurations is the possible occurrence of oscillatory fire. Recently, during large-scale fire experiments performed at the French “Institut de Radioprotection et de Sûreté Nucléaire”, a series of oscillatory behaviour phenomena involving a pool fire in a mechanically ventilated room have been observed. Significant fluctuations of the burning rate were noticed causing large amplitude room gas pressure variations and ventilation flow rate inversions. These fire scenarios are identified as a major concern for fire safety assessments due to a possible loss of the dynamic confinement and the current uncertainty of the prediction capabilities of numerical tools. The loss of dynamic confinement is a major fire hazard in case of oscillatory fire due to the risk of gas release at each cycle of oscillations where high pressure level in the room is achieved.

Several studies have already discussed the oscillatory behaviour of the fire in an enclosure. Two main features of the scenario may induce instabilities: the flow entering the enclosure and the under-ventilated conditions for combustion.

Compartment scenarios with natural ventilation have shown unsteady behaviour of the burning rate and the ventilation factor of the room $AH^{0.5}$ has been pointed out as key parameter [1–4]. For a given value of the ventilation factor, the burning rate shows oscillations with frequencies in the range (0.02, 0.2) Hz. This behaviour has also been observed in the case of a vent connected to the compartment [5–7]. These studies show that oscillatory behaviour of the flow entering and leaving the compartment may be a source for unsteady behaviour of the burning rate.

Oscillatory behaviours with displacement of the flame have also been observed and are often called “ghosting flame”

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Nomenclature List

$\dot{m}$	Mass flow rate (kg/s)
M	Molar mass (g/mol)
HRR	Heat release rate (W)
P	Pressure (Pa)
$\dot{q}''$	Thermal fluxes (W/m3/°K)
Q or qv	Volumetric flow rate (m^3/s)
R	Perfect gas constant
r	Stoichiometric ratio
S	Section (m^2)
t	Time (s)
Tr	Renewal rate (h^{-1})
T	Temperature (°C)
U	Velocity (m/s)
V	Volume (m^3)

Greek

ρ	Density (kg/m^3)
ΔH	Enthalpy (J/kg)

Subscripts

v	Ventilation
$vent$	Vent
adm	Ventilation inlet or admission
ext	Ventilation exhaust
O_2	Oxygen
up	Upward or upper layer
low	Lower layer
f	Fire
$L3$	Lower room L3
ref	Reference

phenomenon in a naturally ventilated compartment [8–10]. These studies highlight the relationship between the oscillatory behaviour and the poor ventilation conditions inside the enclosure. Most of these works have been performed for naturally ventilated enclosures (with an opening to the atmosphere) and only a few research works have described fires in forced ventilated enclosures [11–13].

For some specific scenarios, predictive simulations have been performed. The challenge concerns not only the modelling of each physical phenomenon independently (especially the process of combustion for under-ventilated conditions and local extinction) but also their coupling in time and the possibilities of predicting periodic oscillatory solutions. Therefore, there is still a need to improve the knowledge of such phenomenon in order to be confident on predictions.

The present contribution proposes an experimental and numerical study of the oscillatory behaviour of a pool fire based on large-scale fire tests performed at IRSN in the framework of the OECD PRISME2 project [14]. The scenario is a pool fire in a closed and mechanically ventilated compartment. The objective of this

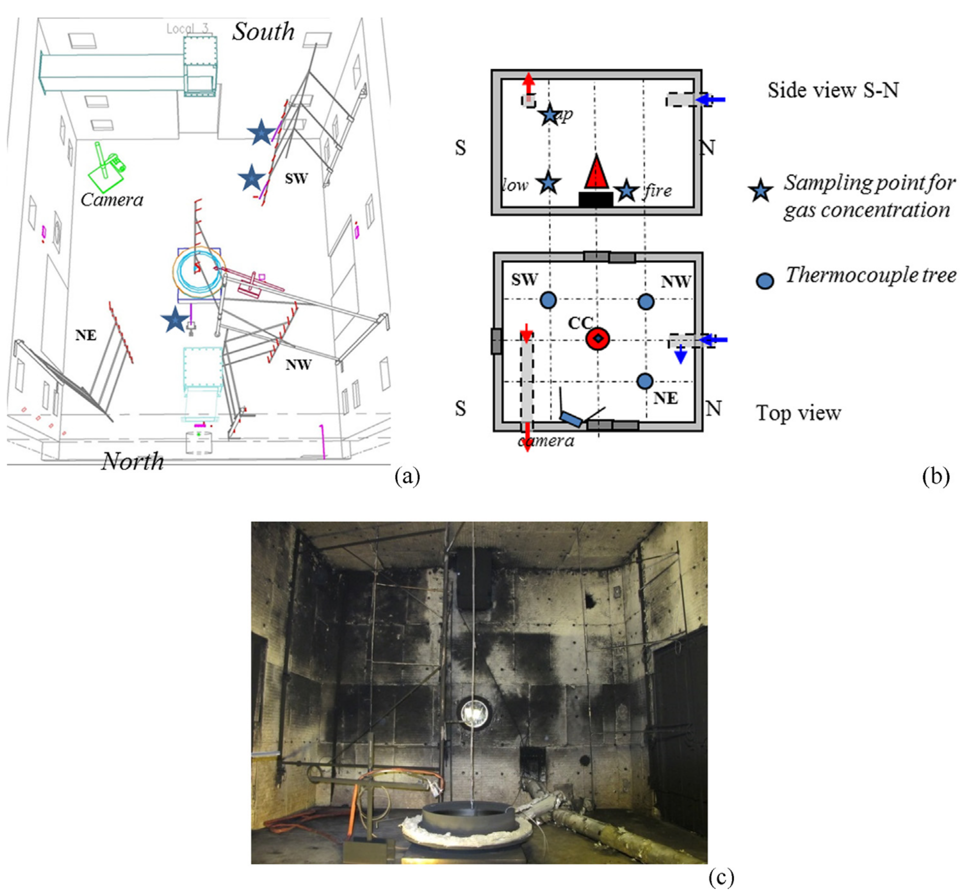

Fig. 1. Description of the facility: (a) location of the measurements; (b) configuration of the enclosure; (c) picture of the north wall.