IMT Mines Alès
École Mines-Télécom

SCIENCE & CREATIVITY TO INVENT A SUSTAINABLE WORLD

PhD Position in

Risk Sciences

Institution	IMT Mines Alès (Ecole Nationale Supérieure des Mines d'Alès)
Main job assignment	Teaching and Research center CREER and Laboratoire d'Expérimentation des Feux LEF.
Administrative residence	Alès (Gard - Occitanie) and Cadarache (Bouches-du-Rhône – PACA)

1. Context

The Institut Mines-Télécom (IMT), a major institution within the meaning of the Education Code, is a public scientific, cultural and professional institution (EPSCP) placed under the principal supervision of the ministers responsible for industry and digital technology. It is the largest group of engineering schools in France, with 11 public engineering schools spread across the country, which train 13,500 engineers and PhDs each year. The ITM employs 4,500 people and has an annual budget of €400M, 40% of which comes from its own resources. IMT has 2 Carnot institutes, 35 industrial chairs, produces 2100 A rank publications annually, 60 patents and carries out 110M€ of contractual research.

Created in 1843, IMT Mines Alès currently has 1,400 students (including 250 foreigners) and 380 staff. The school has 3 research and teaching centers of high scientific and technological level, which work in the fields of materials and civil engineering (C2MA), environment and risks (CREER), artificial intelligence and industrial and digital engineering (CERIS). It has 12 technological platforms and has 1,600 partner companies.

2. Research project

Title: Experimental study of smoke explosions due to reignition of unburned combustion products during a fire in a mechanically ventilated enclosure.

Keywords: Under-ventilated fire, smoke explosion, unburned gases, experimental, aerial overpressure, risks, deflagration

This thesis project will be carried out in partnership with IRSN (Laboratoire d'Expérimentation des Feux) at Cadarache. The main scientific objectives of this research project concern the identification of fire scenarios that could lead to smoke explosion risks, and the modeling of the physical phenomena involved (unburned product kinetics, mixing mechanism in the enclosure, combustion of the mixture and mechanical impact on the enclosure), enabling realistic prediction of the fire scenario. The phenomenon of smoke explosion during a fire has been little studied for the configurations encountered in nuclear installations, resulting in a high level of uncertainty both in terms of our knowledge of the scenarios at risk and our ability to model and assess these scenarios. A third objective is to acquire experimental skills for the study of fast kinetic energy phenomena during a fire.

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Thesis content:

The research topic concerns the explosion phenomena of a flammable gas mixture produced during a fire in a compartment. The scenario of fire in a closed, mechanically ventilated enclosure is widely encountered in the nuclear industry. Under certain conditions, the depletion of oxygen in the enclosure due to a high heat load relative to the volume of the enclosure and/or its ventilation rate, leads to local or total extinguishments and thus to a significant production of “unburnt” gases present in the smoke. These gases can reignite locally through a physical mechanism of rapid combustion (also known as smoke explosion) under certain conditions of mixing with the oxygen present in the room. The consequences are significant pressure increases that can threaten the containment and physical integrity of the enclosure. This topic lies at the interface between the risks induced by fires and explosions, between the physics of diffusion flames and that of premixed combustion, and between weakly compressible and compressible flows.

Smoke explosions during a fire have been identified as a major industrial hazard due to their impact on structures and response teams [1], [2]. The scenarios concern smouldering or developing fires with low ventilation levels, where a significant production of unburnt gases is observed. The work focuses on unburnt gas production and ignition processes [3], but also on the particular scenario known as “backdraft”, encountered in enclosures open to the outside world [4],[5],[6]. It's a complex subject at the frontier between two distinct fields: fire and explosion. It has mainly been studied in open environments or enclosures naturally ventilated by openings (door or vent) [7]. The configuration of a closed, mechanically-ventilated enclosure widely encountered in nuclear installations and in the industrial field has been much less studied [8], [9]. The particularity of this configuration concerns the mixing processes of unburnt gases and their combustion inside the enclosure, unlike the backdraft which occurs outside [10]. Large-scale experiments carried out at IRSN have demonstrated these phenomena for electrical cable fires and in configurations representative of nuclear facilities [11]. The scientific questions that remain concerning these scenarios are the identification of the conditions for obtaining an explosion (nature of the fuel, ventilation configuration, room geometry), the overall sequence of the various processes (production, mixing, ignition and combustion) and the consequences for the installation.

The aim of this thesis is to provide knowledge to be able to perform realistic simulations of these fire scenarios. Various points will be addressed. The first concerns the characteristics of the gas mixtures involved, in particular their flammability and chemical composition (pyrolysed fuel or intermediate gaseous species resulting from incomplete combustion). The range of flammability, the amplitude of flame speeds and the influence of other compounds such as CO or soot are topics of interest. The second point concerns the mechanisms by which combustible species mix with the oxygen present in the room. These are driven on the one hand by fire-induced buoyancy flows such as the thermal plume, under-ceiling flows and infilling, and on the other hand by inertial flows induced by mechanical ventilation of the room. Finally, the last point concerns the mixture ignition and combustion process, in particular flame speed, the shape of the burning volume, the thermal power released and the mechanical consequences on the enclosure induced by the pressure rise.

The originality and interest of this work lies in the complexity of the subject, the interdisciplinarity between fire and explosion, the implementation of a new experimental set-up equipped with advanced instrumentation enabling the description of rapid phenomena and the localization of flammable mixtures, and finally the contribution of new knowledge on smoke explosions in ventilated enclosures.

3. Team supervision and PhD registration

Teaching and Research center CREER
Research team: EUREQUA
Doctoral school: 583 Risques et société

4. Candidate profile

Master 2 or Engineering School, specializing in Energy, Risk, Mechanics, Fluid, Chemistry, Fire Safety Engineering (ISI).

The candidate has to be interested by experimental work, be rigorous and have a good practical sense. The thesis work will involve carrying out tests using high-level instrumentation (high-speed cameras, thermal cameras, high-speed sensors). A good level of English is required (publications and participation in international conferences).

The candidate will work in partnership with a technician and a research engineer, and is expected to be a team player.

5. References

[1] W. M. Croft, “Fires involving explosions — A literature review,” Fire Saf. J., vol. 3, no. 1, pp. 3–24, 1980, doi: 10.1016/0379-7112(80)90003-X.

[2] R. Zalosh, “Explosion Protection,” in SFPE handbook of Fire Protection Engineering, ISBN:08776., SFPE, Ed.

[3] B. Magnognou, J. P. Garo, B. Coudour, and H. Y. Wang, “Risk analysis of unburnt gas ignition in an exhaust system connected to a confined and mechanically ventilated enclosure fire,” Fire Saf. J., vol. 91, no. February, pp. 291–302, 2017, doi: 10.1016/j.firesaf.2017.03.036.

[4] S. Rasoulipour and C. Fleischmann, “Experimental investigation of the smoke explosion phenomenon,” Fire Saf. J., vol. 140, no. July, p. 103881, 2023, doi: 10.1016/j.firesaf.2023.103881.

[5] S. Rasoulipour, “Experimental investigation of smoke explosion phenomenon,” University of Canterbury, 2022.

[6] C. M. Fleischmann and Z. J. Chen, “Defining the difference between backdraft and smoke explosions,” Procedia Eng., vol. 62, pp. 324–330, 2013, doi: 10.1016/j.proeng.2013.08.071.

[7] C. Fleischmann, D. Madrzykowski, and N. Dow, “Exploring Overpressure Events in Compartment Fires,” Fire Technol., vol. 60, no. 3, pp. 1867–1889, 2024, doi: 10.1007/s10694-024-01553-5.

[8] R. Dobashi, “Studies on accidental gas and dust explosions,” Fire Saf. J., vol. 91, pp. 21–27, 2017, doi: 10.1016/j.firesaf.2017.04.029.

[9] R. Dobashi, “Experimental study on gas explosion behavior in enclosure,” J. Loss Prev. Process Ind., vol. 10, no. 2, pp. 83–89, 1997, doi: 10.1016/S0950-4230(96)00050-2.

[10] H. Prétrel, N. Chaaraoui, B. Lafdal, and S. Suard, “Effect of environmental conditions on fire combustion regimes in mechanically-ventilated compartments,” Fire Saf. J., vol. 127, no. June 2021, 2022, doi: 10.1016/j.firesaf.2021.103493.

[11] P. Zavaleta, S. Suard, and L. Audouin, “Cable tray fire tests with halogenated electric cables in a confined and mechanically ventilated facility,” Fire Mater., vol. 43, no. 5, pp. 543–560, 2019, doi: 10.1002/fam.2717.

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