Supervisor :

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Description of the research work proposed for a PhD

Title: Study of the Effect of Flame Oscillation on Fire Hazard Using the CFD Code FDS6.

Keywords: Flame oscillation; Unburnt gases generation, GC-MS analysis,confined environment, CFD FDS6 modelling. .

Subjectif :

I- Context and goal

The dynamics of flame behavior in confined environments play a critical role in fire safety engineering, particularly regarding the risk of fire propagation between compartments [1,2,3,4,5,6,7]. Among these dynamics, flame oscillation—characterized by periodic fluctuations in flame shape and intensity—remains an area requiring deeper exploration due to its potential influence on heat transfer, unburnt gas generation, and ultimately, on the risk of thermal runaway phenomena such as backdraft or flashover [3,4,5,6].
This doctoral research aims to investigate the influence of flame oscillation on fire hazard development through high-fidelity numerical simulations conducted using the computational fluid dynamics code FDS6 (Fire Dynamics Simulator), developed by NIST [8]. The study will focus on fire scenarios arising from gas leaks within sensitive gas storage facilities equipped with mechanical ventilation systems, where the interaction between ventilation, fuel concentration, and oscillatory combustion can significantly affect flame dynamics and the risk of fire escalation [5].
A key objective of the thesis will be to develop and validate a methodology for mapping unburnt gas fields using advanced image processing techniques, in conjunction with experimental gas analyses performed via GC-MS. The simulation results from FDS6 will be used to support and interpret the experimental data, enabling a comprehensive understanding of the physicochemical processes that govern fire progression in oscillatory flame regimes [3,4,10].
This research will be conducted under the supervision of Dr. Brady Manescau, HDR, whose extensive expertise in fire dynamics and flame behavior has been recognized through the publication of over thirty peer-reviewed articles and numerous conference contributions on related topics [1,2,3,5,6,7,9,11]. His guidance will ensure a rigorous scientific approach to investigating these complex phenomena, with the broader aim of contributing to improved predictive tools and safety strategies in fire engineering.

II- Objective and Expected results

This PhD project aims to develop a numerical tool capable of mapping unburnt gases in a confined or semi-confined compartment equipped with a mechanical ventilation system, under fire conditions involving flame oscillation phenomena. The tool will be based on the exploitation and coupling of CFD simulations (FDS6) and experimental data, and will serve

to better understand the influence of confinement and ventilation configurations on the accumulation and spatial distribution of combustible species.
The experimental setup reproduces a gas bottle storage compartment at small scale, fitted with an adjustable ventilation system (door and/or window) to simulate real accidental configurations. The scenario reflects a sensitive industrial environment where unburnt gases may accumulate due to incomplete combustion and inadequate ventilation. Five ventilation configurations will be investigated, each associated with different heat release rates, allowing the study of equivalence ratios ranging from lean to extremely rich mixtures.
The numerical tool will enable spatial mapping of unburnt gas concentrations and identification of potential ignition zones by comparison with known flammability limits. This will allow for a better assessment of the fire propagation risk between compartments, particularly in the presence of thermal accidents such as backdrafts.

Provisional Thesis Plan – 10 Key Stages

1. **Comprehensive literature review**
    - Fire dynamics in confined and ventilated compartments
    - Flame oscillation mechanisms
    - Risk associated with unburnt gases (e.g., backdraft)
    - State-of-the-art in CFD modeling using FDS
2. **Definition of the experimental campaign**
    - Definition of test matrix (ventilation openings, HRR levels, equivalence ratios)
3. **First experimental trials and validation of boundary conditions**
    - Characterization of thermal fields and flow patterns
    - Identification of flame oscillation regimes
4. **Numerical modeling using FDS6**
    - Sensitivity studies on boundary conditions and turbulence models
5. **Development of the digital mapping tool**
    - Integration of simulation data to reconstruct unburnt gas fields
    - Coupling with experimental results for validation
6. **Analysis of the influence of ventilation and confinement**
    - Correlation between equivalence ratio, flame regime, and gas accumulation
    - Identification of risk thresholds for unburnt gas ignition
7. **Cross-validation and refinement of the model**
    - Comparison of numerical and experimental fields
    - Model adjustments to improve predictive accuracy
8. **Application scenarios and risk quantification**
    - Simulation of critical cases (rich mixture, obstructed ventilation)
    - Mapping ignition zones and fire propagation routes
9. **Scientific dissemination**
    - Preparation and submission of three peer-reviewed journal articles (Fire Safety Journal, Process Safety and Environmental Protection, Journal of Fire Sciences)
10. **Writing and defense of the PhD thesis**
    - Structuring of the manuscript around experimental, modeling, and application aspects

III- References

[1] B. Magnognou (Manescau), J. P. Garo, B. Coudour, H. Y. Wang, Risk Assessment of Unburnt Gas Ignition in an Exhaust System Connected to a Confined and Mechanically Ventilated Enclosure Fire, *Fire Safety Journal*, Vol. 91, pp. 291-302, 2017. doi.org/10.1016/j.firesaf.2017.03.036

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