Influence of an obstacle on the behavior of a gravity wave and flow mixing before a backdraft phenomenon

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A fire growth in an enclosure is controlled either by the air or fuel availability. In the first case, oxygen is consumed by combustion up to extinction when the equivalence ratio and the reactant dilution rate reach the flammability limit. The high temperature in the enclosure can sustain the pyrolysis and the off gassing of the fuel load; fuel degradation products fill the compartment containing combustion products, nitrogen and un consumed oxygen.

When opening the door, a cool dense air flow enters into the chamber outwardly expelling the hot fluid. This gravity wave propagates through the compartment. At the interface between the gas streams, cold (air) and hot (fueled) fluids are mixed. Reactants can be ignited by a hot point if the flammability limit, the residence time and the temperature conditions are locally reached. A premixed flame propagates towards the aperture and outside of the enclosure like a blast: the backdraft phenomenon is occurring.

The objective of this work is to describe this gravity wave behavior during its incoming into the enclosure. Particularly, investigation is focused on the formation and evolution of thermal instabilities during the flow propagation, which act on the fluid mixture. The effects of the aperture position and of an obstacle on the gravity wave propagation are studied.

An original laboratory scale experimental device was designed and built to reproduce, in inert environment, the aero-thermal conditions leading to the formation of a gravity wave by providing a temperature difference between the inside and outside of the enclosure. The set-up consists in a box of dimension L=0.55m; l=0.50m; H=0.41m thermally insulated. A lateral window allows optical measurements. To reproduce the thermal conditions representative of a backdraft, the enclosure is electrically heated at its rear.

The temperature difference $\Delta T$ between ambient and enclosure at the door opening is adjusted at 125, 175 and 225°C. The inside temperature is homogenized by a fan located in the upper zone of the box. The wave development is investigated for two positions of the 0.16m high motorized doors (bottom or middle of the front side of the enclosure).

In this work, the influence of an obstacle (0.04m height) located in the gravity wave trajectory is also characterized. All trials are performed with inert gases. For safety consideration, flame ignition and propagation are not considered.

Time-Resolved PIV measurements are performed (125 vector fields/s) to characterize the gravity wave. The instantaneous and mean velocity fields are investigated to determine the influence of the door position (bottom or medium) and of the obstacle on the mixing between fresh and hot gases.

KelvinHelmholtz structure formation at the aperture

The results describe the motion and the mixing rate of the fluids linked to the formation of Kelvin-Helmholtz structures. The compressing and the expensing of the flows during the vortex passage induce an observed pulsatile flow. It is found that the wave characteristics are a function of root mean square of $\Delta T$, the aperture position (flow velocity increases by the root mean square of the height of the step), the obstacle deviates the wave and induces the formation of recirculation zones upstream and downstream of it. The wave crawls along the floor with a maximum of gas velocity $V_h$ at few millimeters from the ground following the above trends. The mixing is mainly performed by the vortex at the interface between fresh and hot flows.

Horizontal velocity component $V_h$ variation

$\Delta T$, the aperture distance from the floor and the presence of an obstacle on the wave displacement modify the gases mixing, the propagation time to a potential ignition zone (hot point) and the residence time in this zone to allow the chemical ignition. The standard hydrostatic law reproduces well the wave behavior particularly for the door position.