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Combustion of a single aluminum droplet burning in O2/CO2/N2 mixtures

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Background

Metal combustion has an interesting **energetic potential** and an elevated temperature flame. According to its high energetic density, **aluminum micrometric particles** are currently used in industrial solid propellants, especially to **increase thrust** of solid rocket motors (SRM). However, aluminum particles combustion is a complex process sensitive to many parameters. Indeed it is already proved that combustion time depends on particle diameter. Thus, the initial particle size impacts combustion dynamic and larger particles burn as vapor flame in a **diffusion mode** whereas smaller particles combustion occurs in a **kinetic-limited regime**. Relying on experiments, different other factors like **pressure** or **ambient composition** change the aluminum **burning time** and determination of dependence with influencing parameters is an ongoing effort to elaborate accurate correlations, especially in less documented atmospheres such as CO, CO_2 or H_2O which are oxidizers released by solid propellant combustion.

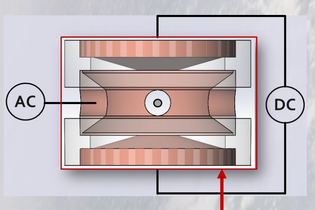
Objectives

Explain and quantify influence of ambient SRM conditions on combustion process analyzing single burning aluminum particle :

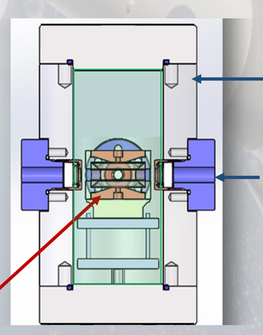
- Development of an experimental technique with high-speed image processing
- Determination of combustion time dependence to improve numerical simulations
- Improvement of phenomenological understanding

Experimental set-up

- **Single aluminum particle (30-150µm) is isolated in an electrodynamic levitator confined in a high pressure chamber supplied by various gases [1].**



Electrodynamic levitator



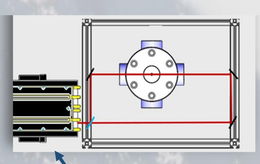
HP chamber

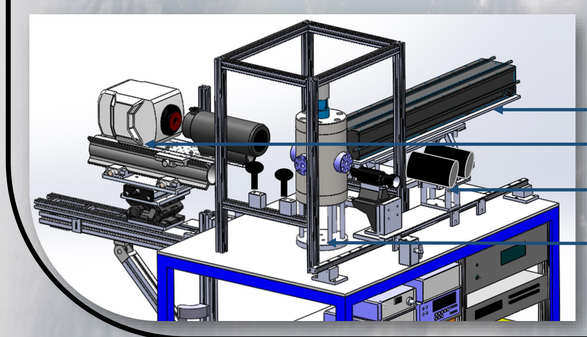
Optical access

Ambient Gases :

- O_2
- N_2
- Ar
- CO_2
- H_2O
- CO

- **Autonomous combustion is initiated by using a separated CO_2 laser beam.**
- **Optical signature of burning aluminum particle is recorded using filtered photomultipliers and a high-speed camera.**

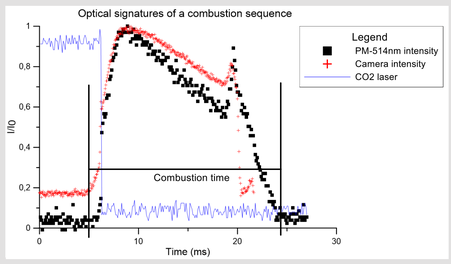




CO_2 laser
High speed camera (25000 fps)
Photomultipliers (540 nm / 488 nm)
HP chamber + levitator

Results

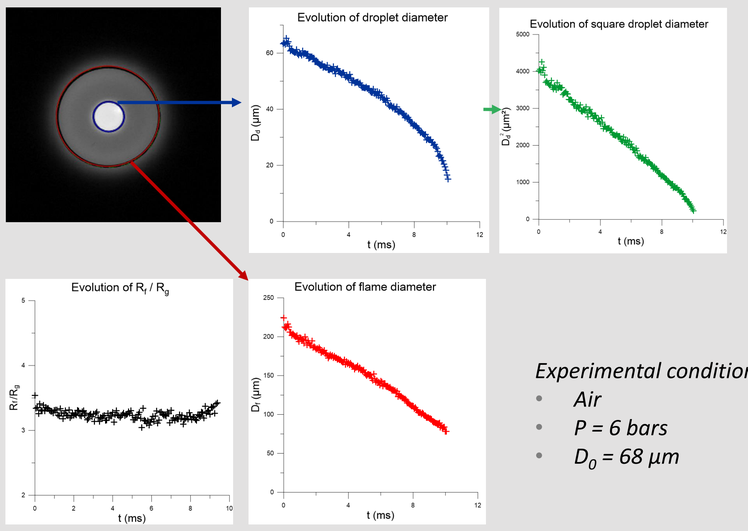
- **Recording of optical emissions and laser signal during combustion sequences**



Experimental conditions
- *Air*
- *P = 1 bars*
- *D_0 = 95 µm*

➢ Combustion time
➢ Temporal identification of singular emissions
➢ Confirmation of laser extinction

- **Recording of dynamic combustion sequences**

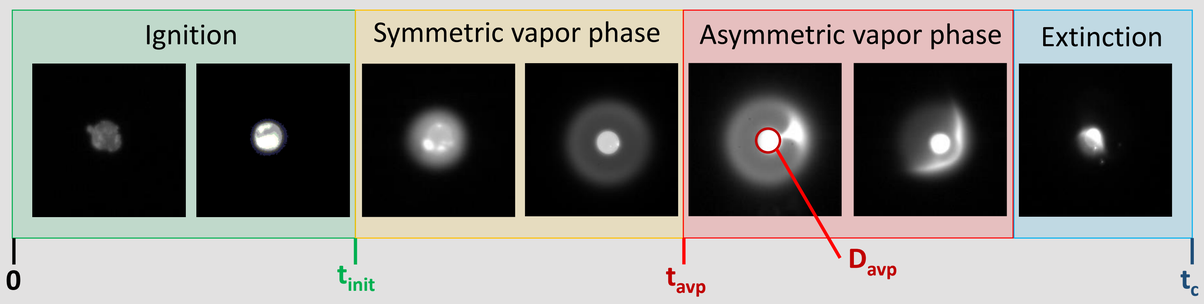


➢ Combustion time t_c
➢ Initial droplet diameter D_0
➢ Evolution of droplet diameter D_g
➢ Evolution of flame diameter D_f
➢ Identification of phenomena

Experimental conditions
- *Air*
- *P = 6 bars*
- *D_0 = 68 µm*

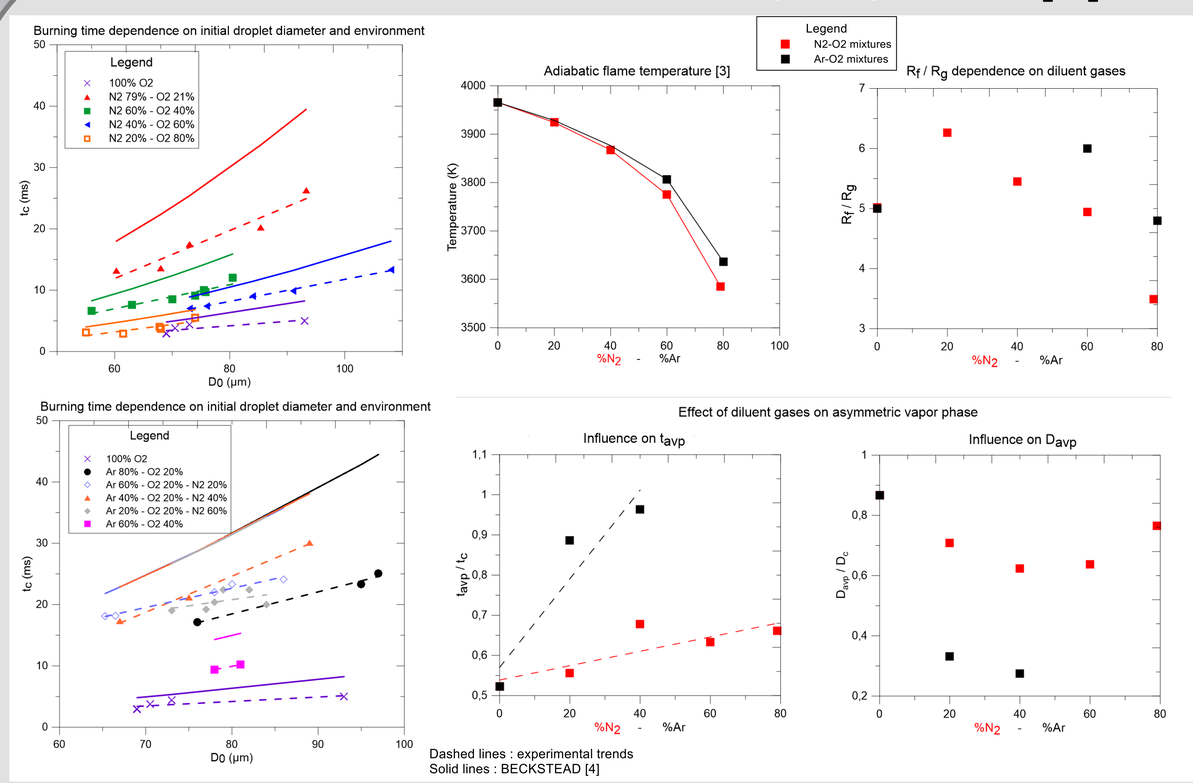
- **Highlighting the existence of different stages [2] of combustion**

Experimental conditions :
- *Air* • P = 1 bars • *D_0 = 90 µm*



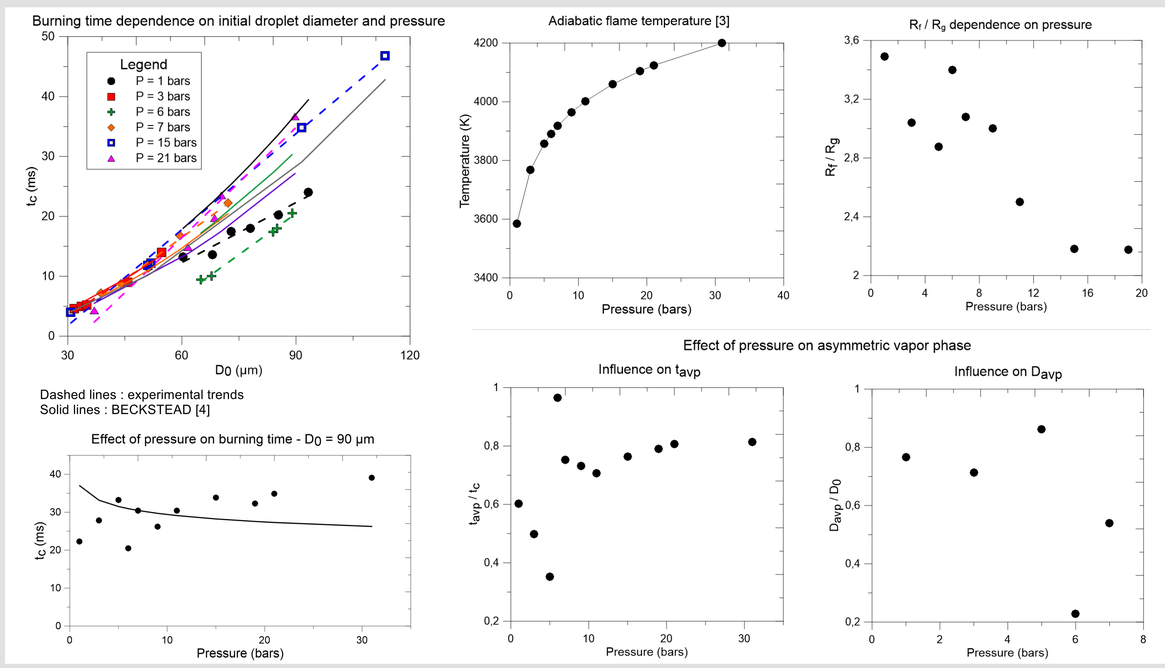
➢ Existence of a symmetric and **a**symmetric **v**apor **p**hase (avp) regimes
➢ Introduction of related parameters : t_{avp} and D_{avp}, respectively time and droplet diameter before asymmetric phase occurrence.

- **Combustion in various mixtures at atmospheric pressure : O_2-N_2-Ar**



- Varying diluent environment, both in composition and proportion, modify combustion times and related parameters of asymmetric vapor phase.
- N_2 and Ar species have similar influences on combustion dynamic but N_2 has a more considerable effect, favoring the apparition of asymmetric vapor phase in comparison with Ar.

- **Combustion in air at various pressure : 1 to 31 bars**



- Varying pressure in a low range seems to modify related parameters of asymmetric vapor phase. Influence of higher pressure is then less considerable.

Future works

- Further investigations to understand and quantify the occurrence of asymmetric phase and its influence on burning parameters varying surrounding composition and pressure.
- Determine correlations between burning time and initial diameter based on regression ratio estimated by image processing.
- Analyze combustion of aluminum particles in CO_2, CO, H_2O vapor and mixtures.

References :

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