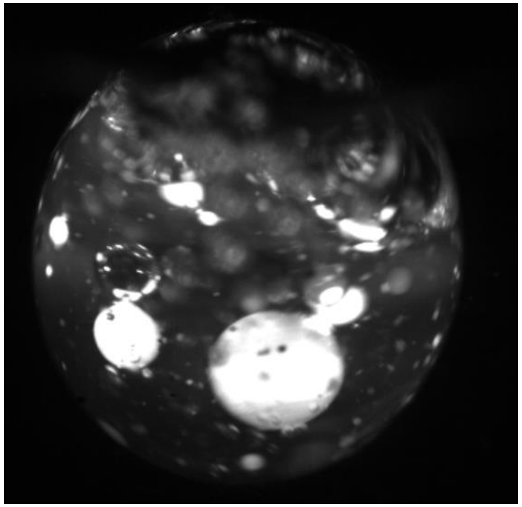
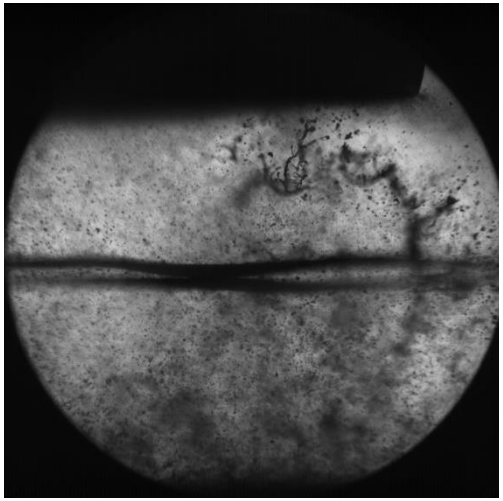
Experimental study of water-in-oil droplet micro-explosion using LIF measurements : effect of radiative heating configuration





T. Naudin [1,2], D.Tarlet[1], R. Calabria[2], P.Massoli[2], J.Bellettre[1]

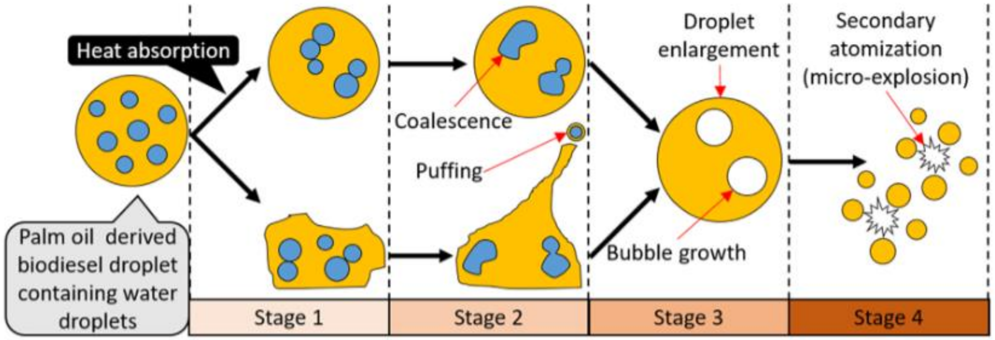
[1]LTeN – Nantes University, Nantes, France

[2]STEMS-CNR – Napoli, Italy

PRESENTATION CONTENTS

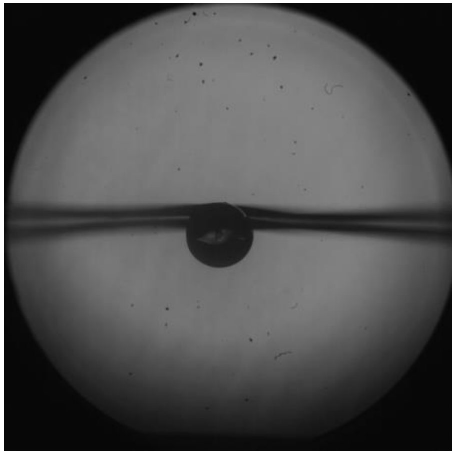
- **Introduction & context of the study**
  - Water-in-oil emulsions and its effect on combustion
  - Aim of the study
- **Material & methods**
  - Experimental bench presentation
  - Laser Induced Fluorescence technique for visualization
- **Results**
  - Effect of Emulsion Mean Diameter on coalescence rate
  - Impact of radiative heating
  - Natural convective motion of the water subdroplets
- **Conclusion & discussion**

- Biofuels : W/O Emulsion (Continuous phase fuel, dispersed phase water + surfactant)
- Reduce Pollutant emissions (CO, NO_x , soot particules)
- Micro-explosion phenomenon :
  - Results from difference in vaporization temperature between Water and Oily Phase
  - Shows a stochastic behavior
  - Enhance Air/Fuel mixing

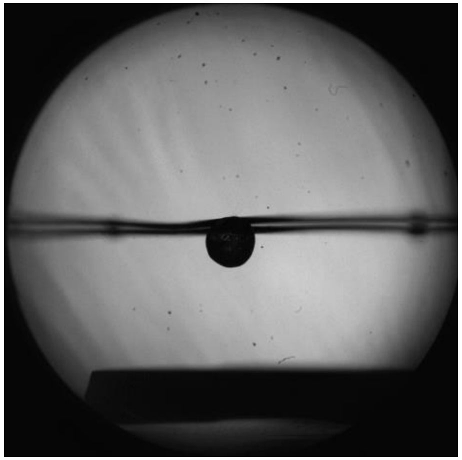


[1]*Masharuddin et al., Alexandria Engineering Journal vol. 61, 2022*

Micro-explosion :



(a) **non-optimal micro-explosion (puffing)**



(b) **Optimal micro-explosion**

Parameters governing the occurrence of micro-explosion :

- Size of the dispersed (water droplets) phase:
  Coarse Emulsion ➔ fast coalescence and high micro-explosion rate and intensity
  Fine emulsion ➔ more stable (low coalescence rate, weak micro-explosion (puffing)
- Composition (% of water and Surfactant)
- Heating Type (conductive, convective or radiant)

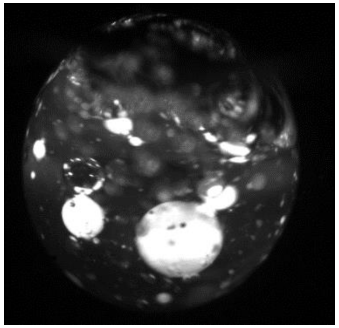
example of coalesced water droplet within an emulsion

Coalescence is a fondamental process for the obtention of micro-explosion

Objectives of the study :

- Understanding better the «life» of the water embedded droplets during the heating phase ➔ natural internal convection
- Investigate the effect of IR radiant heating on emulsion atomization

Emulsion study



Example of LIF setup for water phase visualization

- Require **non-intrusive** methods (optical diagnostics)

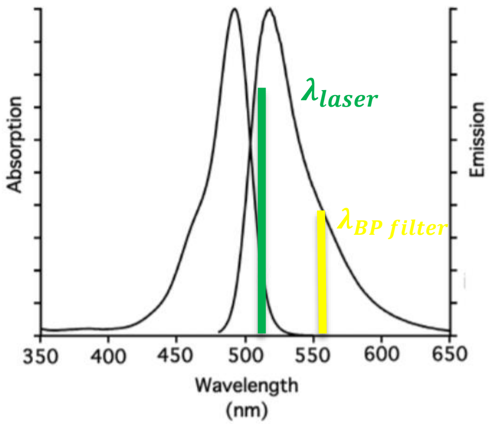
Observation of the water droplets embedded within the Emulsion droplets:

- Require the use of **Laser Induced Fluorescence** technique

Working process of LIF technique :

- Water phase mixed with fluorescent dye **only soluble in water**

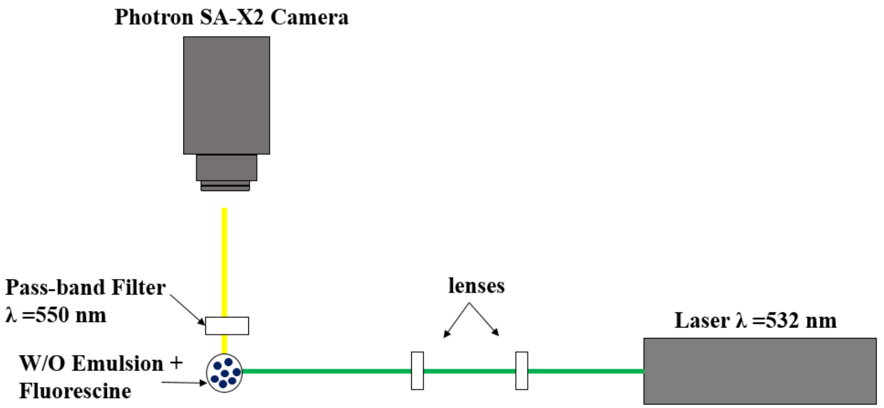
→ Here Fluorescein Sodium Salt (highly soluble in water, absorption spectrum corresponding to the laser wavelength)



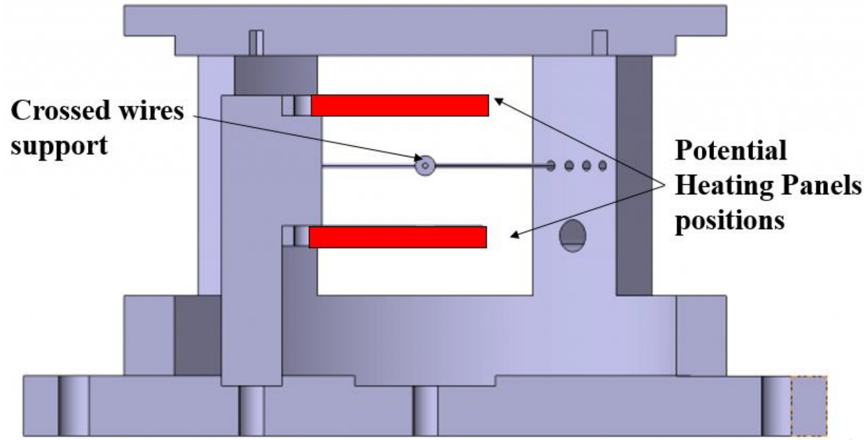
Absorption and Emission spectrum of Fluorescein sodium salt

Experimental Setup

- Water seeded with fluoresceine is excited by a continous laser (λ =532 nm)
- Re-emitted light is filtered with Pass-Band Filter at λ =550 nm
- Images are recorded with Fast camera [500-2000] FPS
- Emulsion is heated by two radiative panels. Temperature is varied between 400 and 700°C.

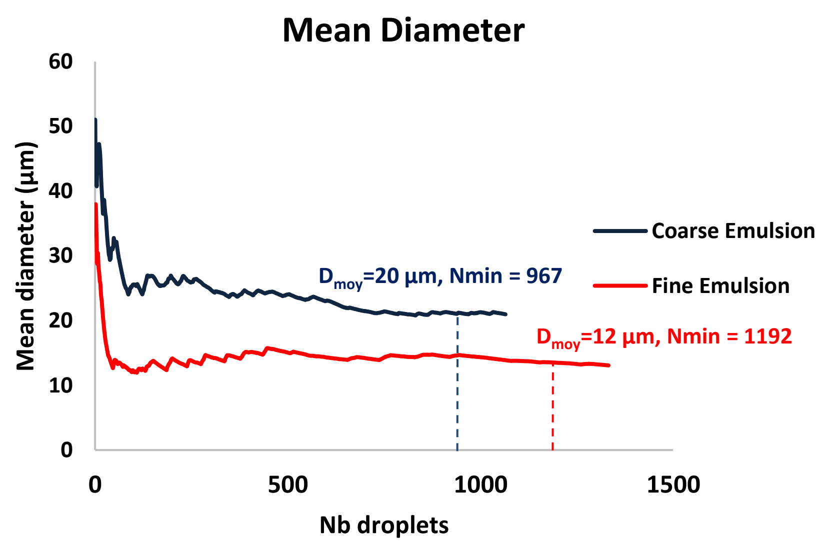


Experimental LIF Bench



Parameters of the study

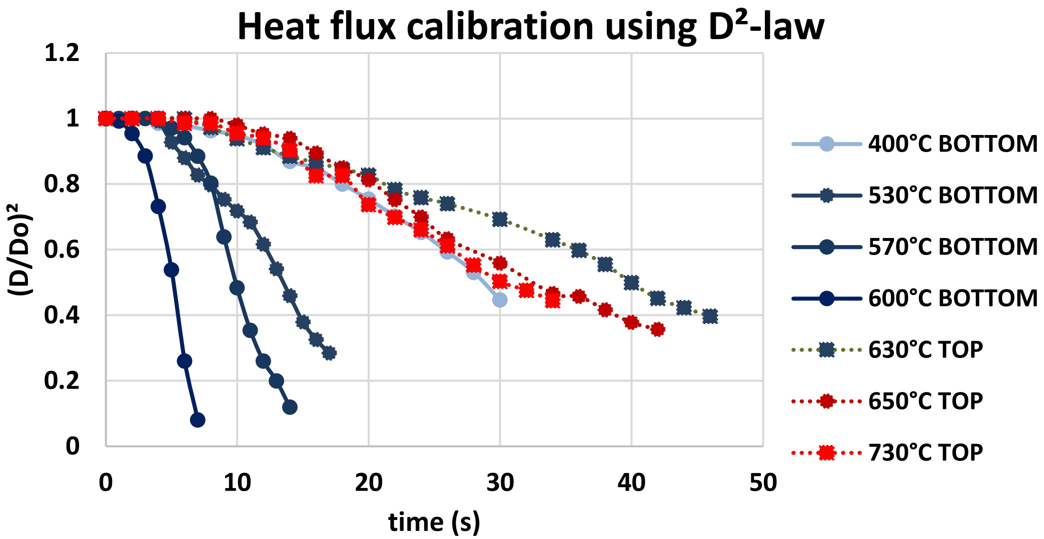
- Two emulsions, same composition(7%$_{mass}$ of water, 0.4%$_{mass}$ of SPAN 83 surfactant, and n-tetradecane) with different MD for the water phase.
- Coarse Emulsion with a MD of 20 µm and Fine Emulsion with a MD of 12 µm.
- Two heating configurations :radiative source at the top or the bottom of the droplet.

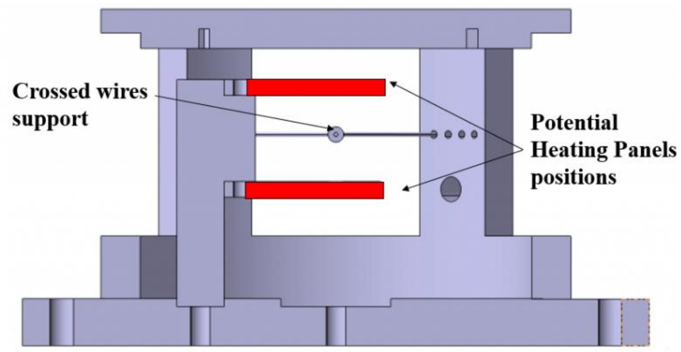


Measurements performed with digital microscope (confidence interval 95%)

Configuration	Water droplet mean diameter (µm)	Heat source location
A	20	Bottom
B	20	Top
C	12	Bottom
D	12	Top

Calibration of the Heat Flux for pure n-tetradecane



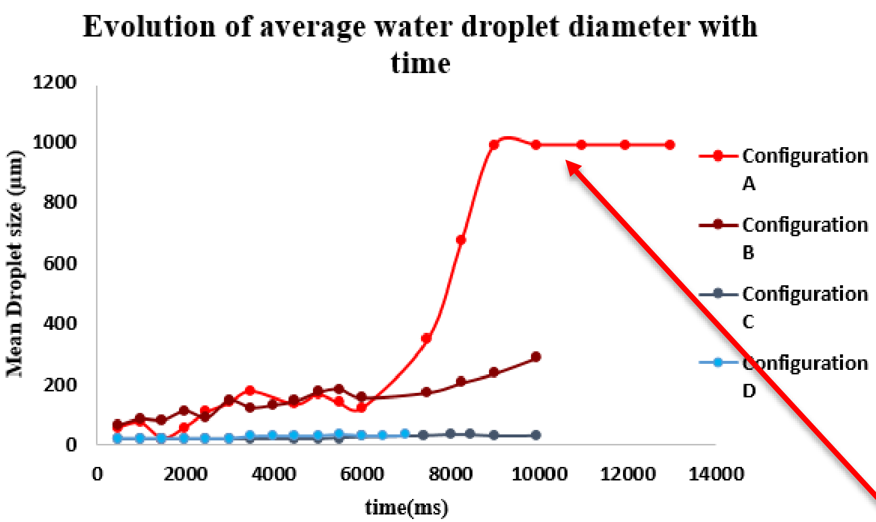


Top heat source :
-**Radiative** and **conductive** heat fluxes

Bottom heat source :
-**Convective** and **radiative** heat flux

- Calibration curve to obtain equal heat flux in top and bottom configuration
- Best Fitting betweeen 700°C TOP and 430°C BOTTOM
- Limitation : performed for pure n-tetradecane (optical properties ≠ of emulsion)

Coalescence rate and micro-explosion rate for different configurations

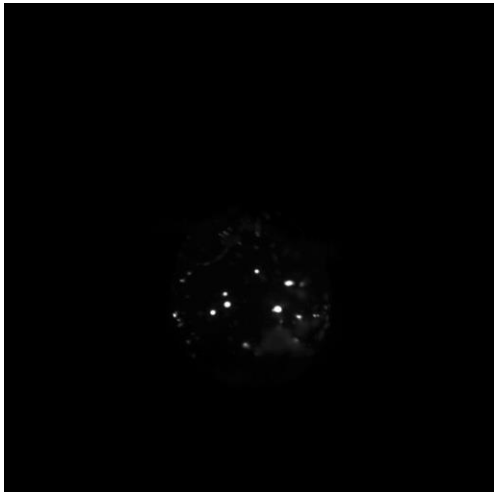


Configuration	ME rate (%)	Average ME delay (s)	ME delay range [max-min] (s)
A	80	16.4	[7.7-27.1]
B	50	18.3	[9.9-25.8]
C	0	N.A	N.A
D	0	N.A	N.A

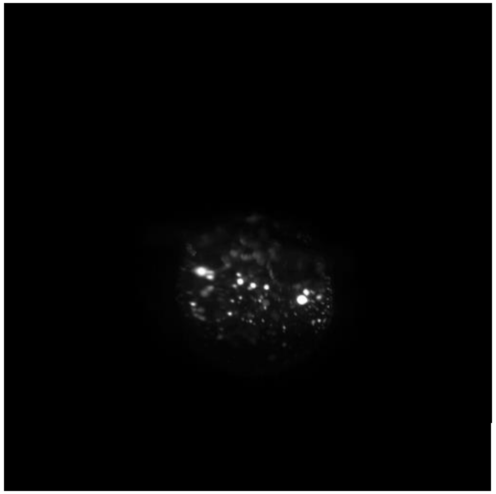
The average ME delay can be decrase to 1.5 -5 (s) by increasing T_{panel}

- Coarse emulsion → strong coalescence rate
  → high micro-explosion %
- Fine emulsion → low coalescence rate
  → almost no micro-explosion. water droplet undergo high internal convective motion

Internal convection in the case of fine emulsion



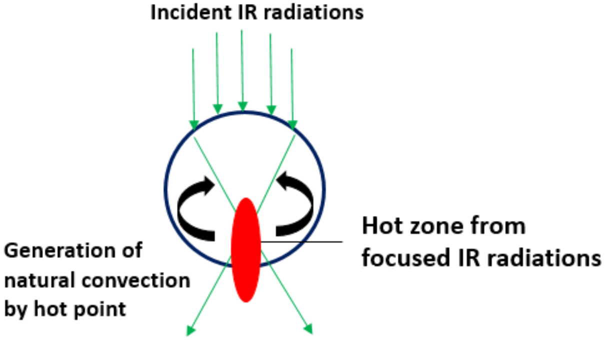
25 x slow down movies



Bottom heat source

Top heat source

- Convective motion in **both** heat sources positions, but only **For fine emulsions**
- For top configuration, **auto-focusing of radiation** involved



Simplified model for radiation in the emulsion droplet

Mains hypothesis **:**

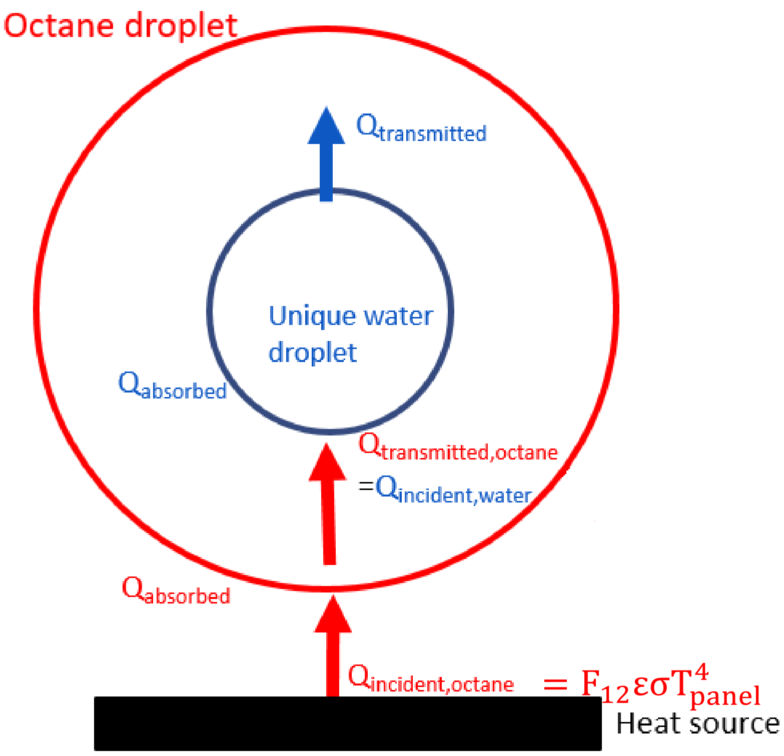
- Typical model for solid and bulks liquids
- Optical properties (refractive index, **taken at constant temperature**)

$$A = 1 - \rho\left(1 + \frac{(1-\rho)^2\tau^2}{1-\rho^2\tau^2}\right) - \frac{(1-\rho)^2\tau}{1-\rho^2\tau^2} \quad \leftarrow \text{absorptivity}$$

$$\tau = e^{-\kappa d} \quad \leftarrow \text{transmission coefficient}$$

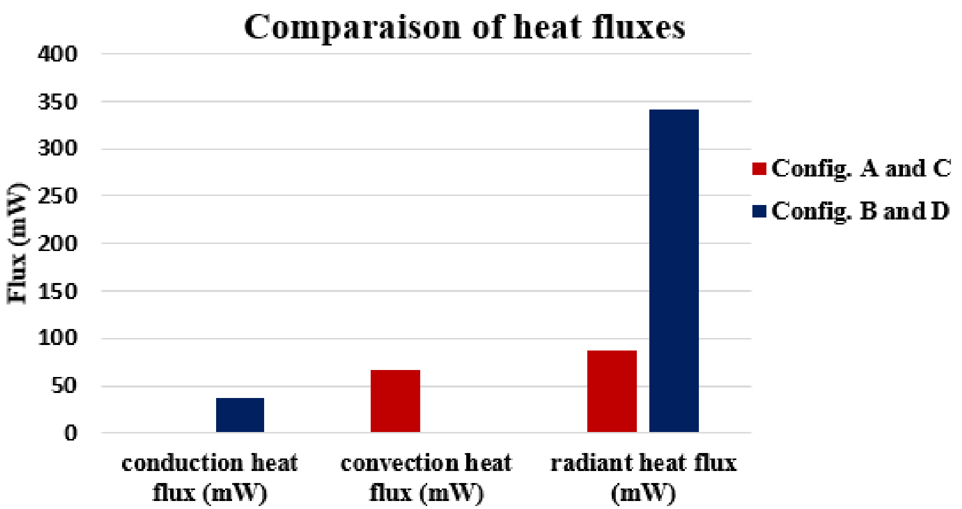
$$\rho = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} \quad \leftarrow \text{Reflection coefficient}$$

- **Single water droplet** located in the center of the emulsion droplet
- **n-octane** instead of n-tetradecane



Contribution of the different modes of heat transfer

- **Conductive, convective and radiant fluxes** are calculated for the two panels configurations
- **The time-independant model** is assumed
- For the bottom panel config., **radiant** and **convective** fluxes are of the same **order or magnitude**
- For the top panel config., **radiant** heat flux is **higher** (because T=700°C with respect to 430°C in bottom config.)



$$Q_{cond} = \frac{\lambda_{air} S(T_{panel} - T_s)}{t_{air}}$$

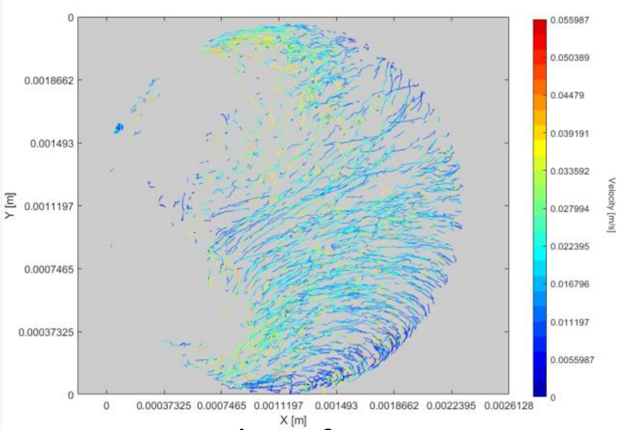
$$Q_{conv} = hS(T_{panel} - T_{air})$$

$$Q_{rad} = \int_{\lambda 1}^{\lambda 2} Q_{abs,water,\lambda} d\lambda + \int_{\lambda 1}^{\lambda 2} Q_{abs,octane,\lambda} d\lambda$$

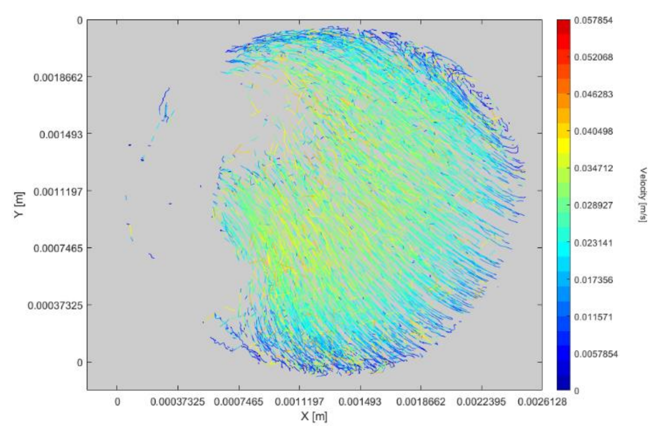
Results

Analyze of the internal convective motion of the water droplets

- Particle-Tracking Velocimetry Algorithm is used for trajectories measurement
- This measurement has been possible due to the LIF that allows to get water droplets centers and radii for each pictures analyzed
- Natural convection observed for **fine emulsions only** (small MD and low coalescence rate)



Top panel configuration



Bottom panel configuration

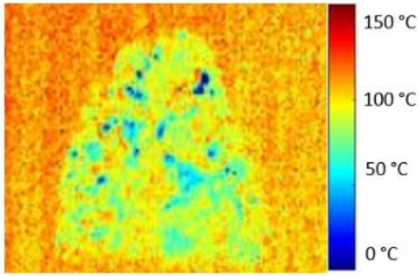
Conclusion & discussion

Conclusion and perspectives

- Laser Induced Fluorescence technique has been used in order to investigated dispersed **water droplet behavior** during heating phase of emulsion
- Coalescence of water droplets **is an influent parameter in order to obtain micro-explosion**
- For fine dispersed water droplets, **internal convection has been observed**, with dependance on the **heating source location** and **type** (radiative or radiative + convective).
- Internal convection **does not promote coalescence**

Next steps of the investigation :

- **More accurate model for analysis of radiation absorption** (Lorenz-Mie theory, Optical Geometry theory or Coated Sphere theory…)
- **two-colors LIF technique :** obtaining **temperature field within the emulsion** droplet.

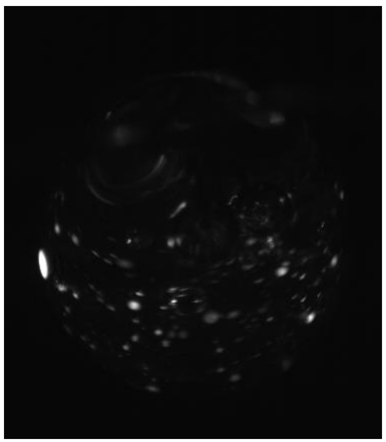


[2] *Moussa et al., Experimental Thermal and Fluid Science vol. 116, 2020*

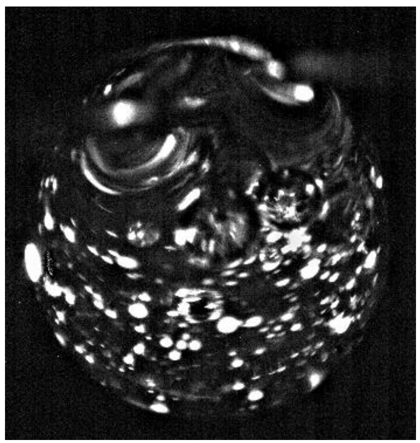
Thank you for your attention

The authors thank the Region Pays de la Loire (Chaire ConnectTalent ODE) for the financial suppot

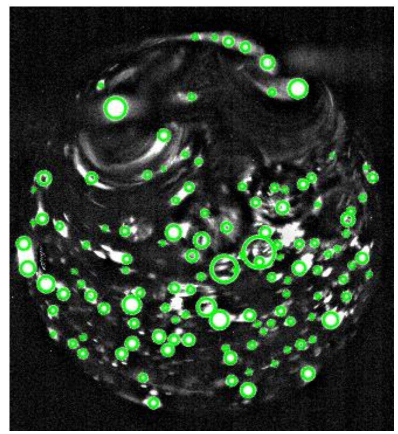
Droplets detection for size and trajectories measurements



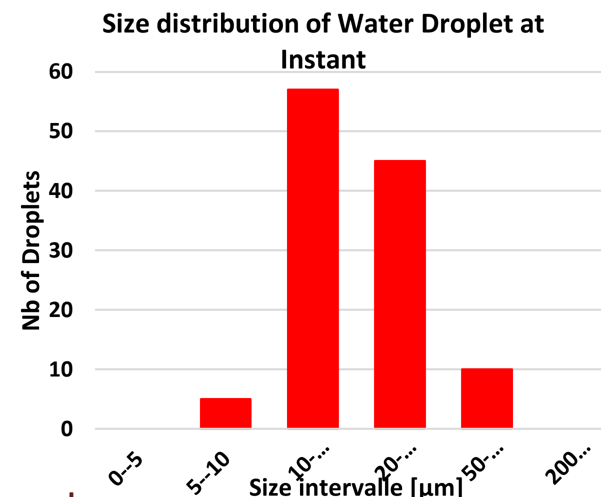
Raw image



Filtering



Size measurement



- Droplets center position and size measured with image post-treatement
- Particle Tracking Velocimetry algorithm is used for trajectories and velocity measurements