Paris, France, Febbruary 28th and March 1st, 2017

PASSAM Final Workshop

Pool Scrubbing and Hydrodynamics in Demi water, Sea Water and with Additives

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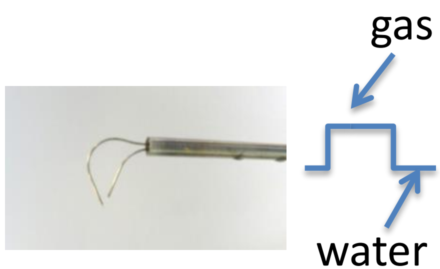
Bubble hydrodynamics:

- optical probe data analysis compared with image analysis
- evolution of bubble size distribution and velocity along Z axis in demi water
- bubble size distribution and velocity in different liquid phases (Sea water, Water with surfactant)

Aerosol Decontamination:

- **0.4 µm - 1 µm** SiO_2 aerosol decontamination measures in demi water pool
- **0.4 µm** SiO_2 aerosol decontamination measures in sea water and water with surfactant pool

Aerosol Decontamination Model



Optical double probe Parameters :

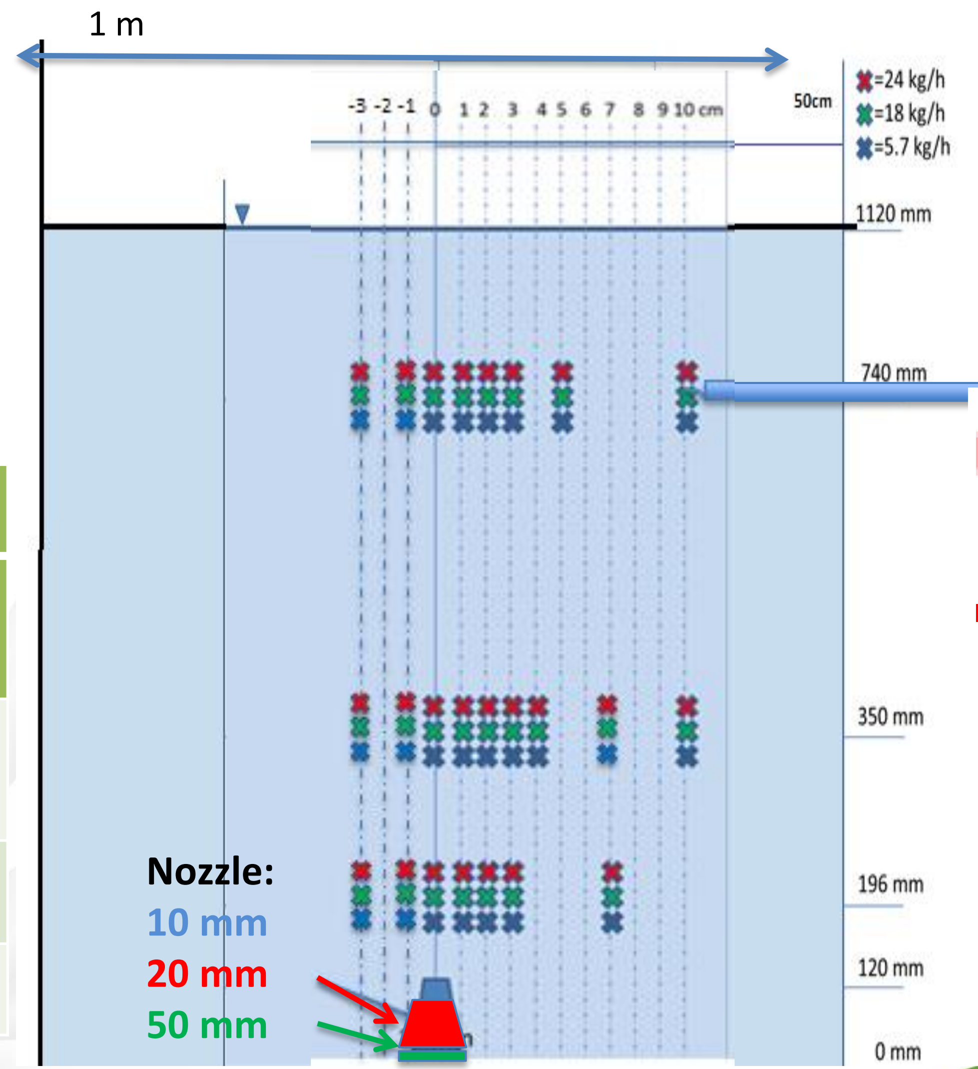
- Void Fraction
- Bubble size
- Bubble velocity

Photo camera Parameters :

- Bubble size
- Bubble shape

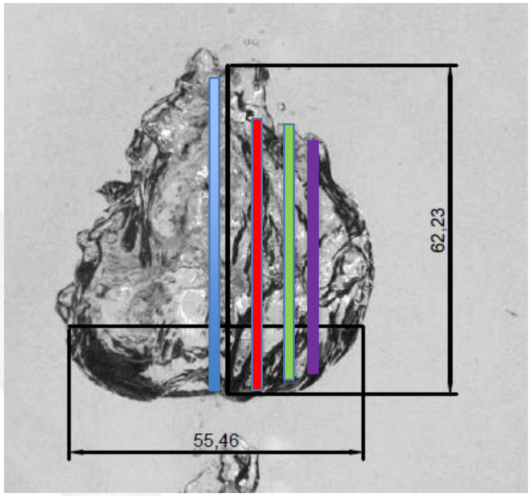
Test Matrix		
Orifice Diameter	**Gas Mass Flow Rate**	**Liquid**
10 mm	**6-18-24 kg/h**	**Demi water Sea water With surfactant**
20 mm	**18-24 kg/h**	**Demi water**
50 mm	**24 kg/h**	**Demi water**

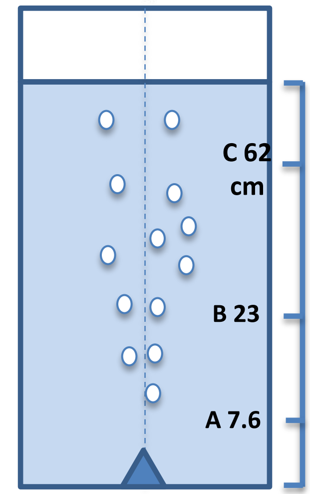
SCRUPOS Facility



Bubble regime

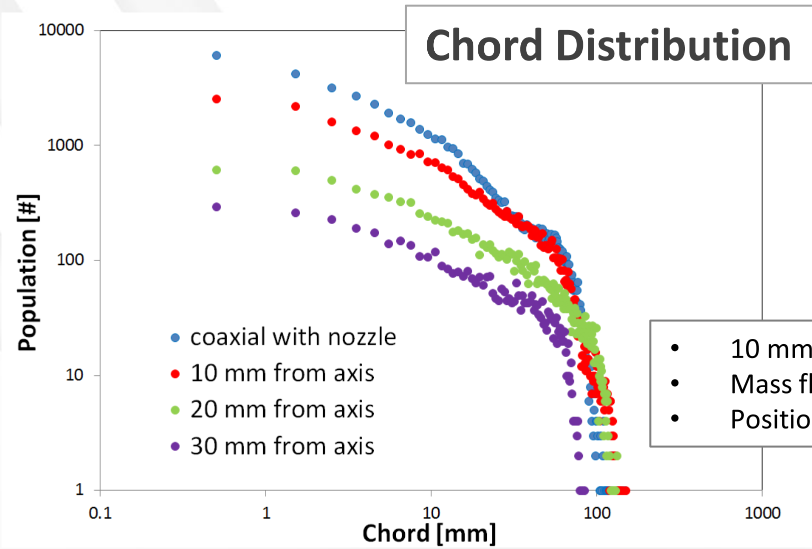
We=3.8*10^4 – v$_{injection}$ =16 m/s - Injection zone - Demi water-



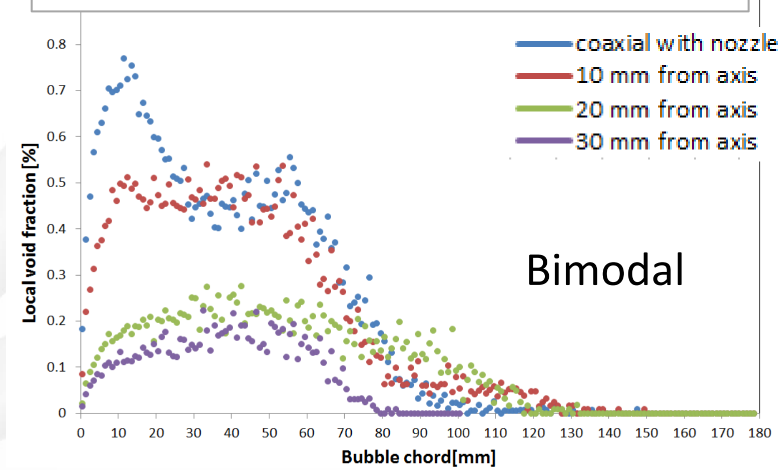


Investigation Method:
Chord distribution vs Local void fraction distribution

Image	Local void distribution[mm]	
Diameter [mm]	First peak [mm]	Second peak [mm]
58	10	60



- 10 mm Nozzle
- Mass flow 5.7Kg/h
- Position (A)

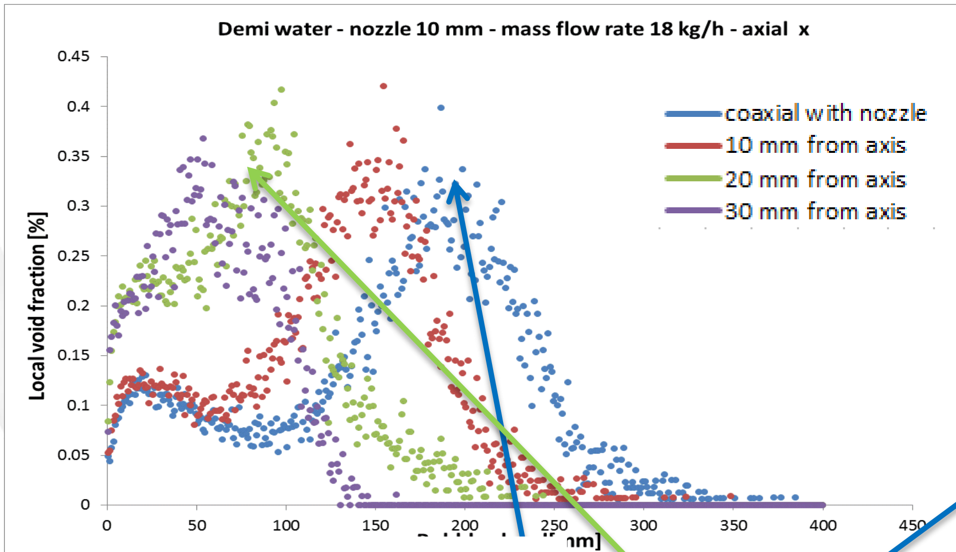


Population chord length /(velocity * time acquisition)*

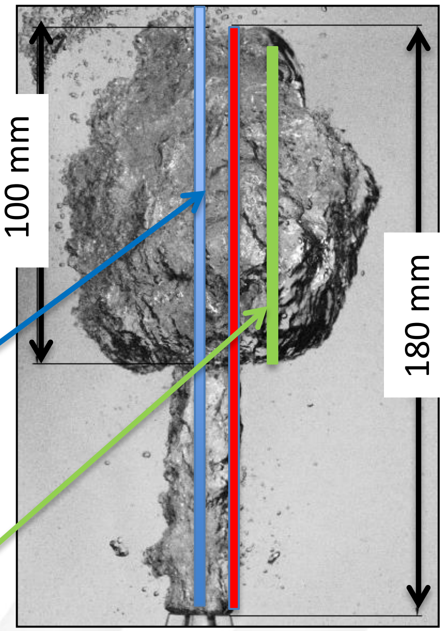
Jet regime

We=3.9 10^5 - $V_{injection}$ =53 m/s - Injection zone – Demi water

Position (A)



Chord lenght [mm]



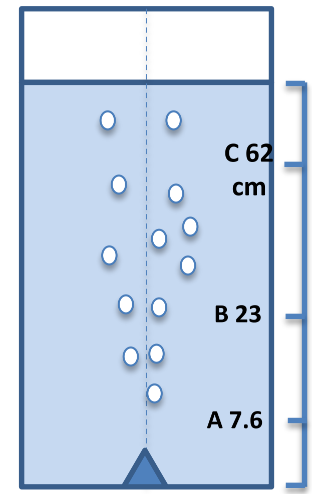


Image	Local void distribution[mm]		
Diameter [mm]	Coaxial with nozzle		30 mm from axis
	First peak [mm]	Second peak [mm]	Peak [mm]
94	19	187	97

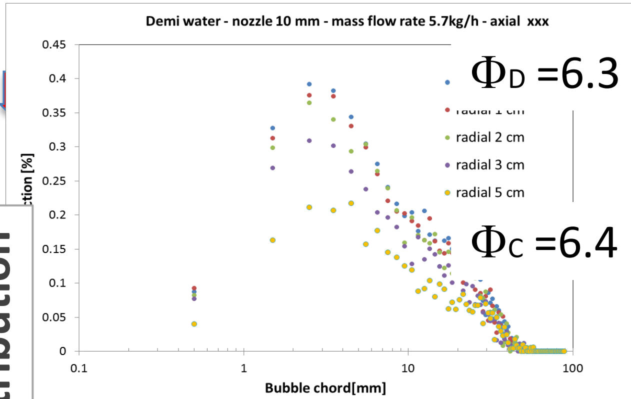
The local void distribution at different radial position corresponds to a scan of the chords of the bubbles when the bubble dimension is larger than the step.
This elaboration well describes the bubble

Bubble regime: We=3.8*10^4

Bubble size distribution evolution

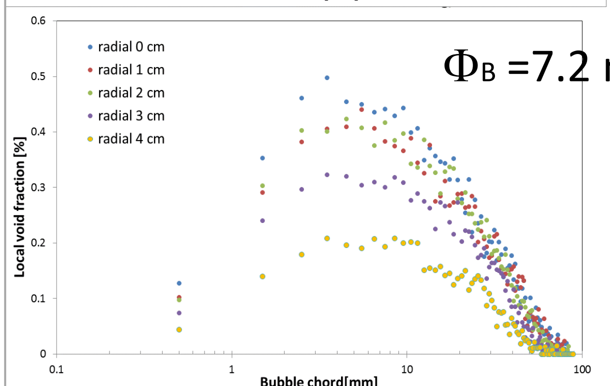
Jet regime: We=7*10^5

Local void fraction distribution

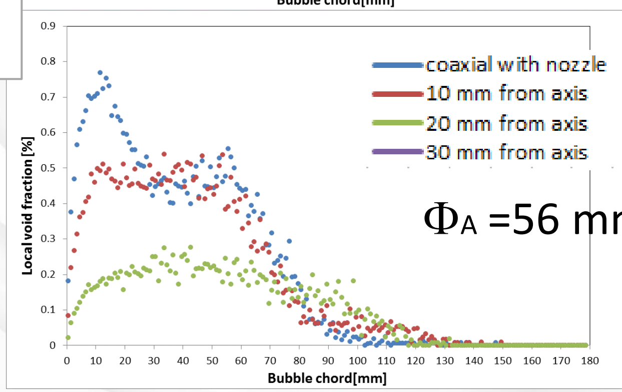


Φ_D =6.3 mm

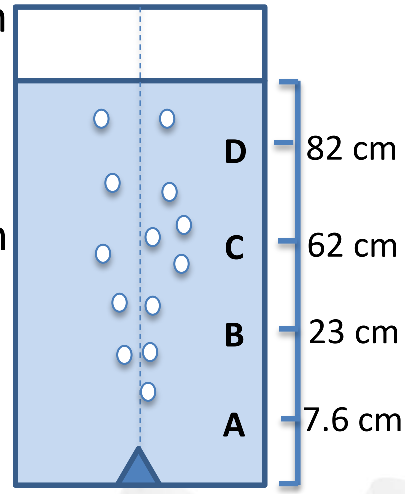
Φ_C =6.4 mm



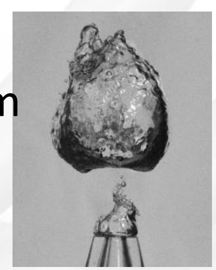
Φ_B =7.2 mm

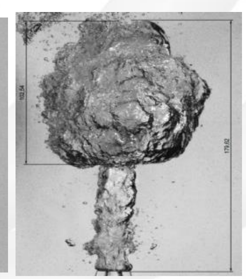


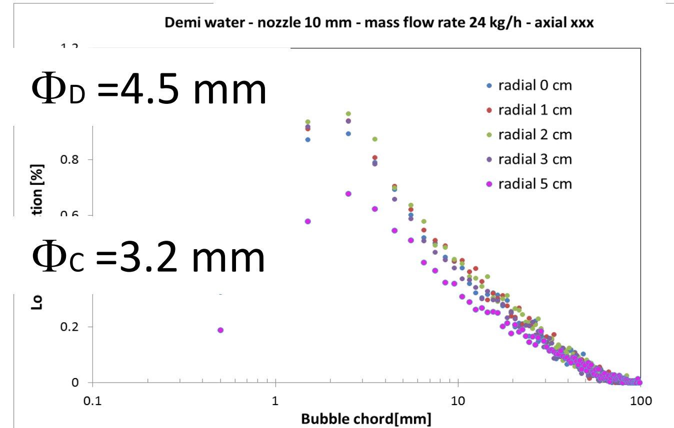
Φ_A =56 mm



$$We = \frac{\rho_l u^2 d}{\sigma} \geq 12\,\zeta(E)$$

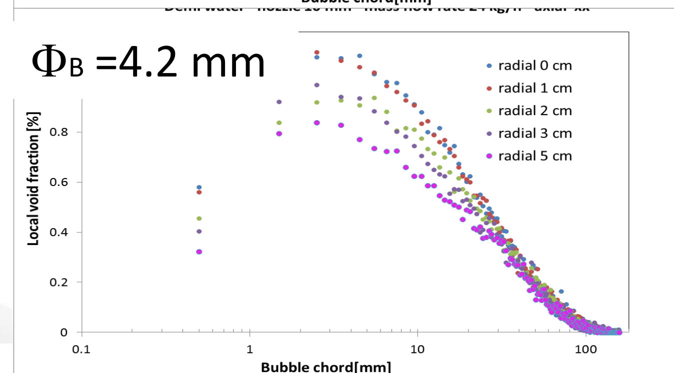






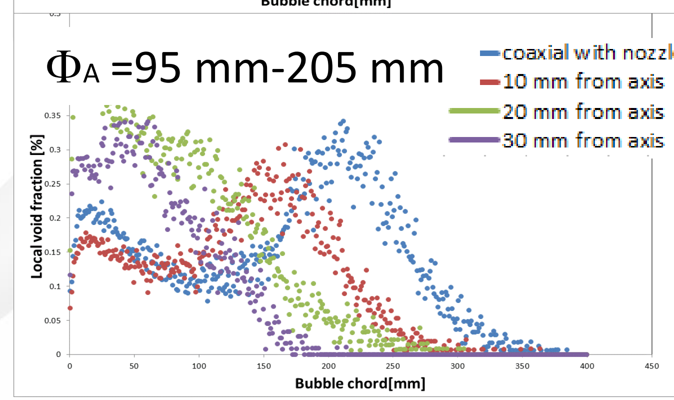
Φ_D =4.5 mm

Φ_C =3.2 mm



Φ_B =4.2 mm

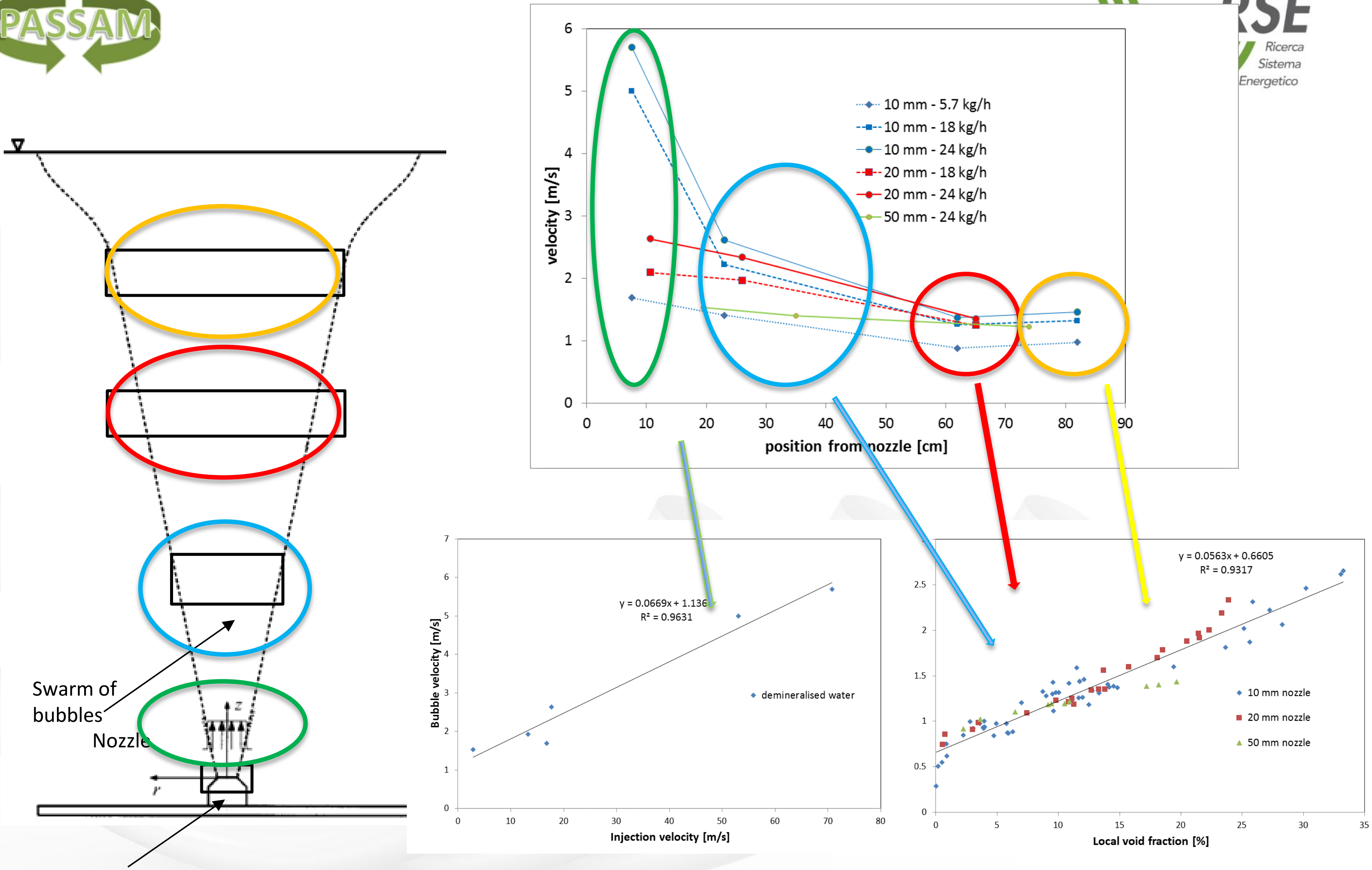
Φ_A =95 mm-205 mm



Φ =equivalent diameter

churn turbolent bubble in injection zone

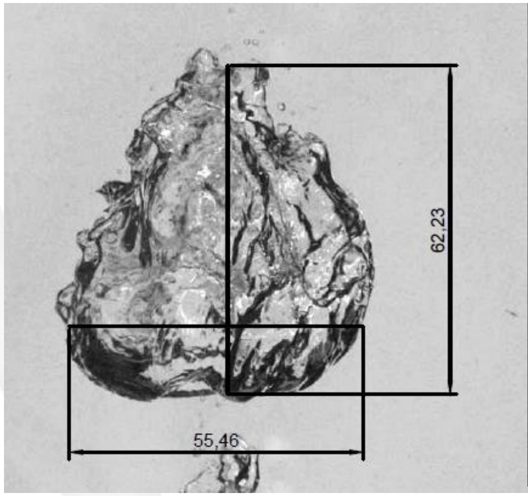
WP 3.1 Tests- Velocity

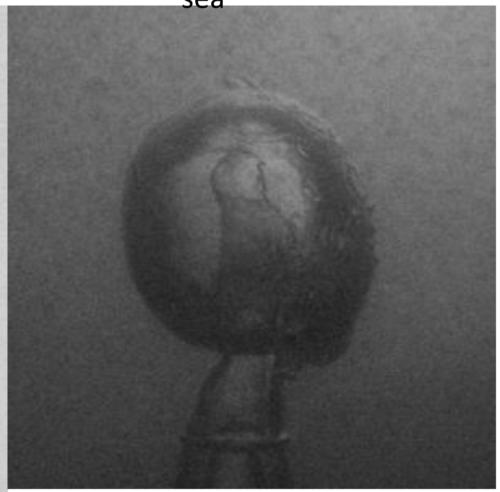


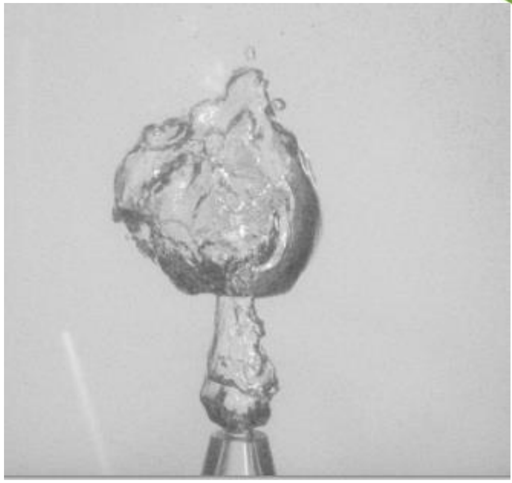
PASSAM

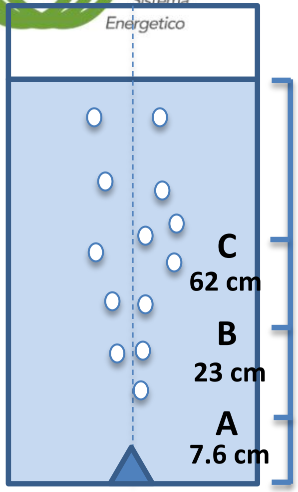
RSE Ricerca Sistema Energetico

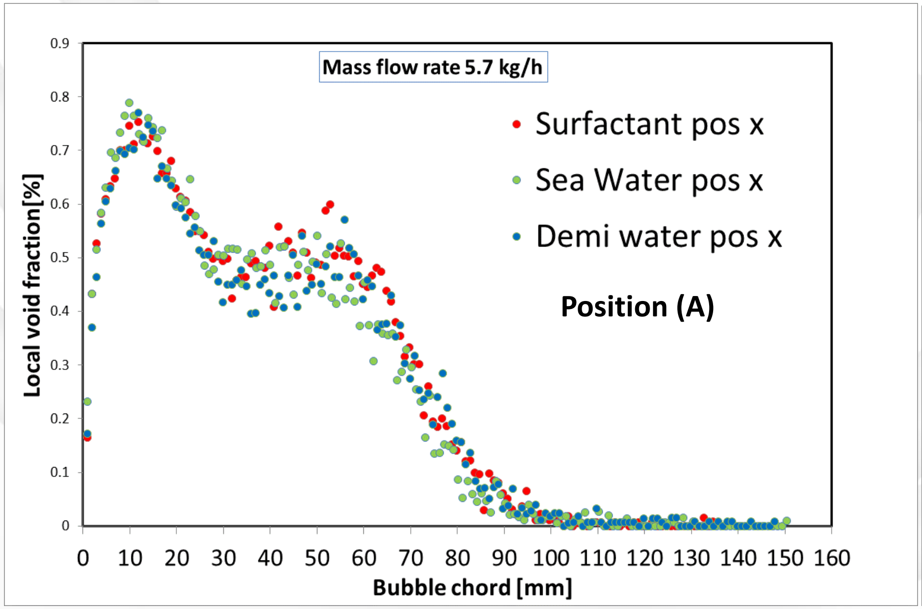
Demi water	Sea Water	Demi with Surfactant
$We_{water} = 3.9*10^4$	$We_{sea} = 4*10^4$	$We_{surf} = 7.8*10^4$

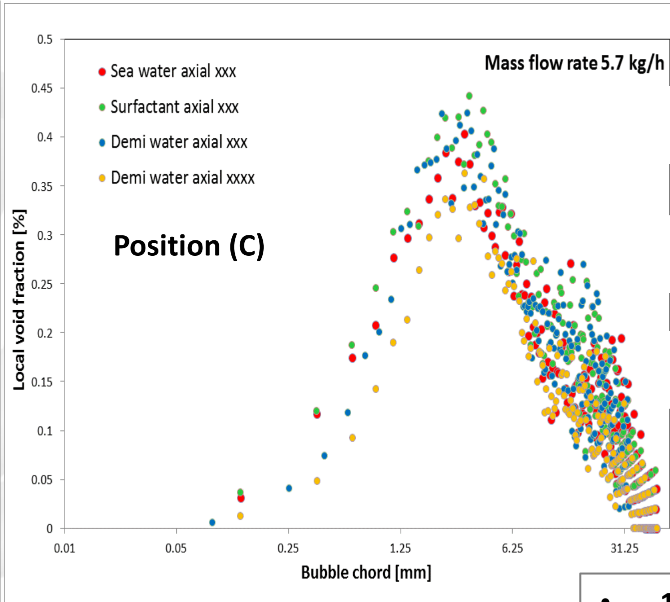












$\Phi_W = 6.4$ mm

$\Phi_{sea} = 5.2$ mm

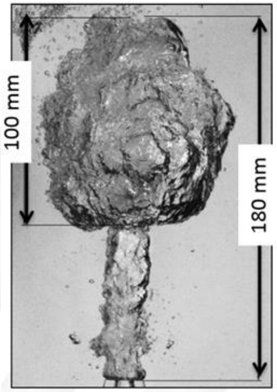
$\Phi_{surf} = 5.8$ mm

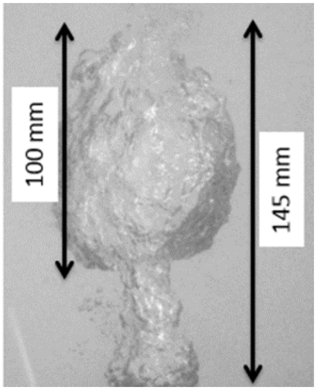
- **10 mm Nozzle**
- **Mass flow 5.7 kg/h**

WP 3.1 Tests- Different liquid phases- Jet regime

- 10 mm Nozzle
- Mass flow 24 kg/h
- Position A

Jet regime We_{water}= 6.9*10^{5}- We_{sea}= 7.1*10 ^{5}- We_{surf}=13.9*10^{5}



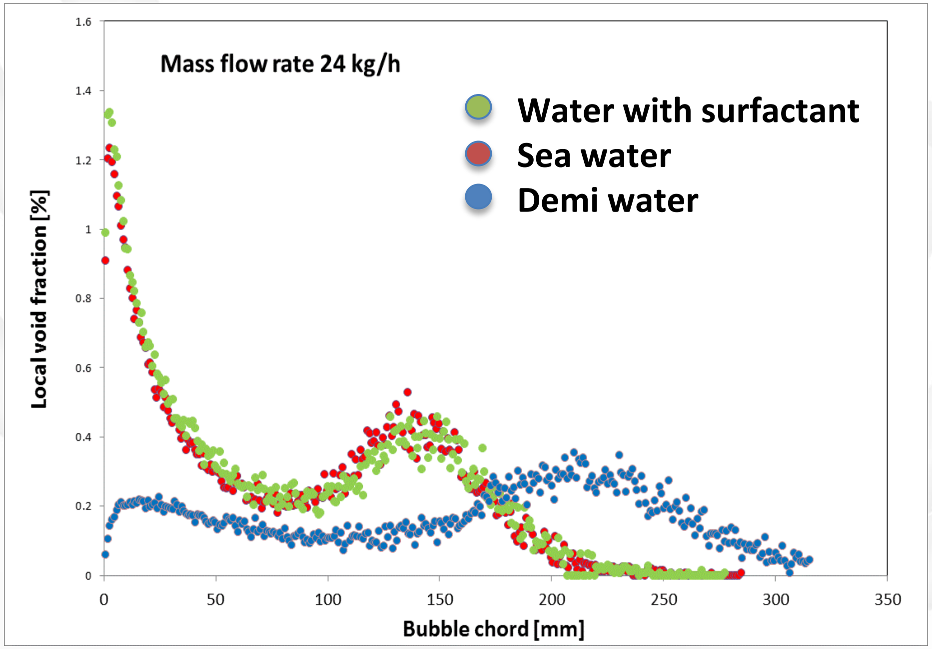


Sea and surfactant:

- smaller "jet column"
- a big number of small bubbles

Water with surfactant:
- smaller surface tension → smaller bubble

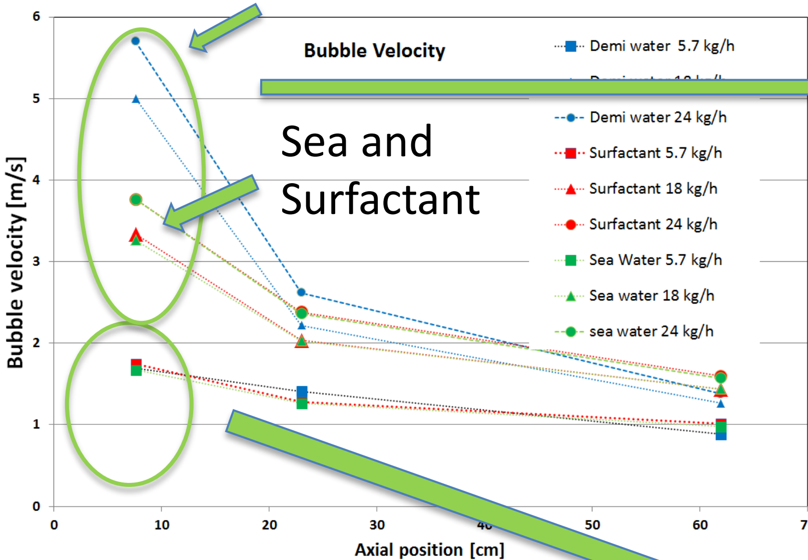
Sea water:
- microscopic structure affects coalescence and break up



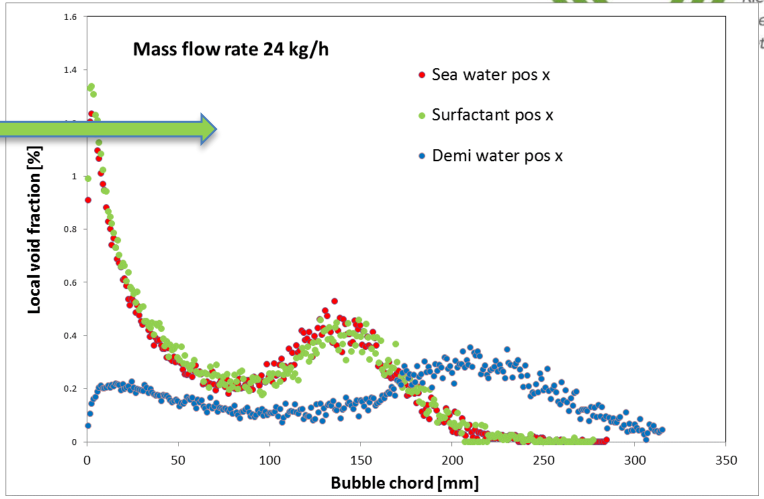
Coalescence efficiency depends on the contact time for the two bubbles and the times required for coalescence of bubbles that is the time required for the liquid film between bubbles to thin from an initial thickness to a critical value where rupture occurs. Salts are found to inhibit bubble coalescence by retarding the thinning of the intervening liquid film between bubble pairs. (**Prince, Blanch 1990)**

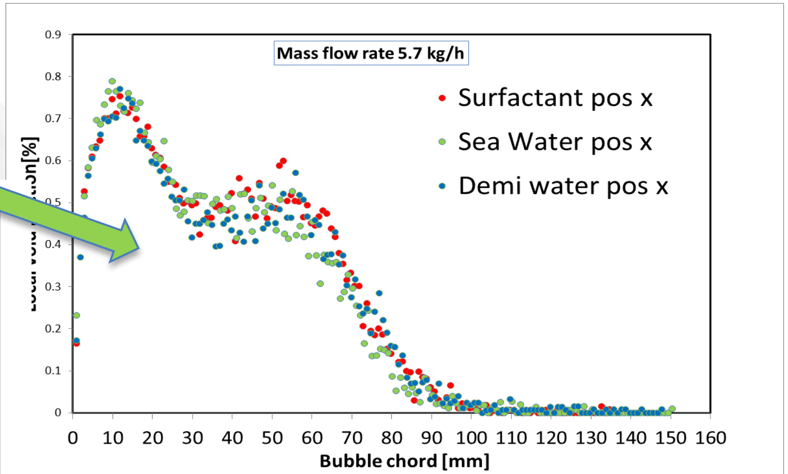
WP 3.1 Tests- Bubble Size

Demi

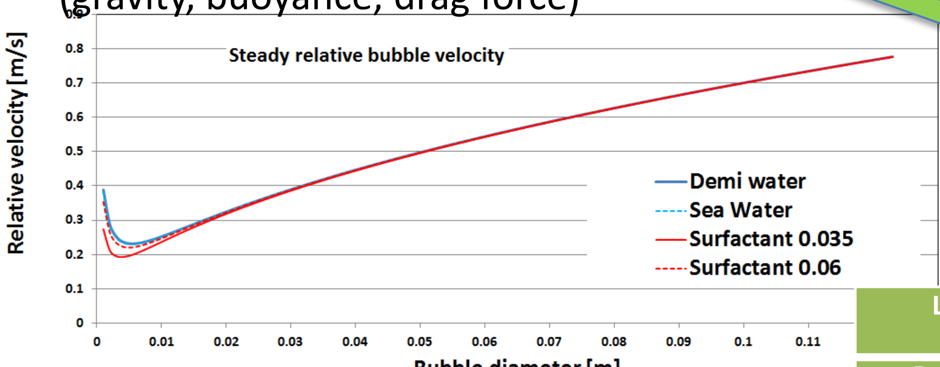


Sea and Surfactant





Steady relative velocity (gravity, buoyance, drag force)

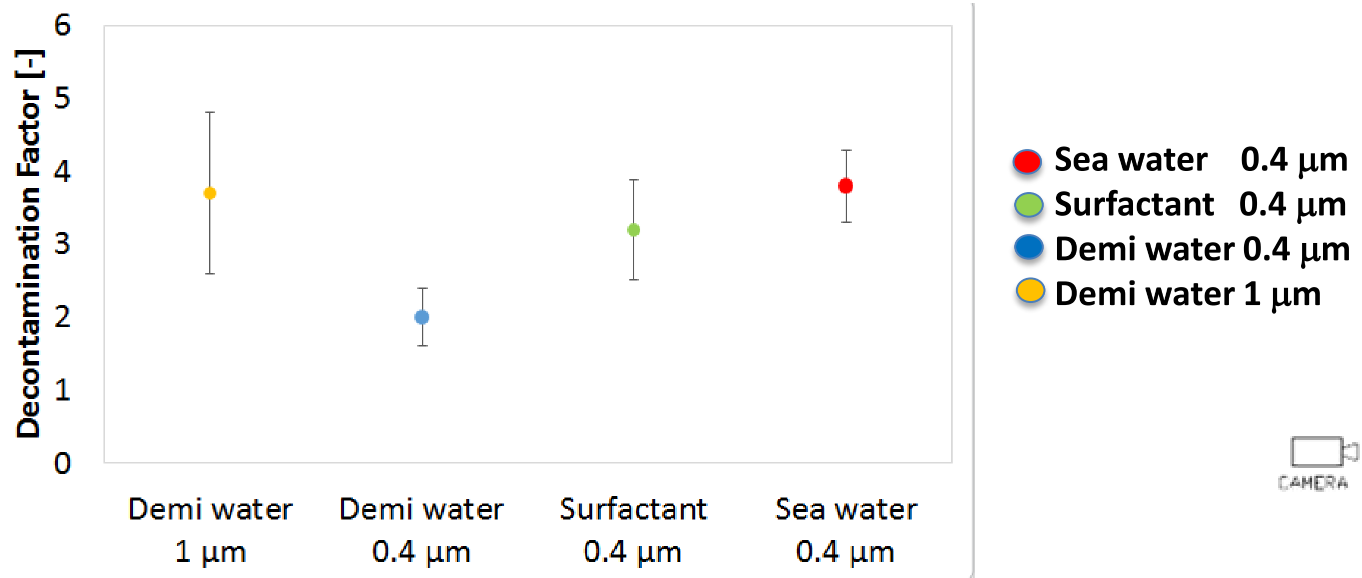


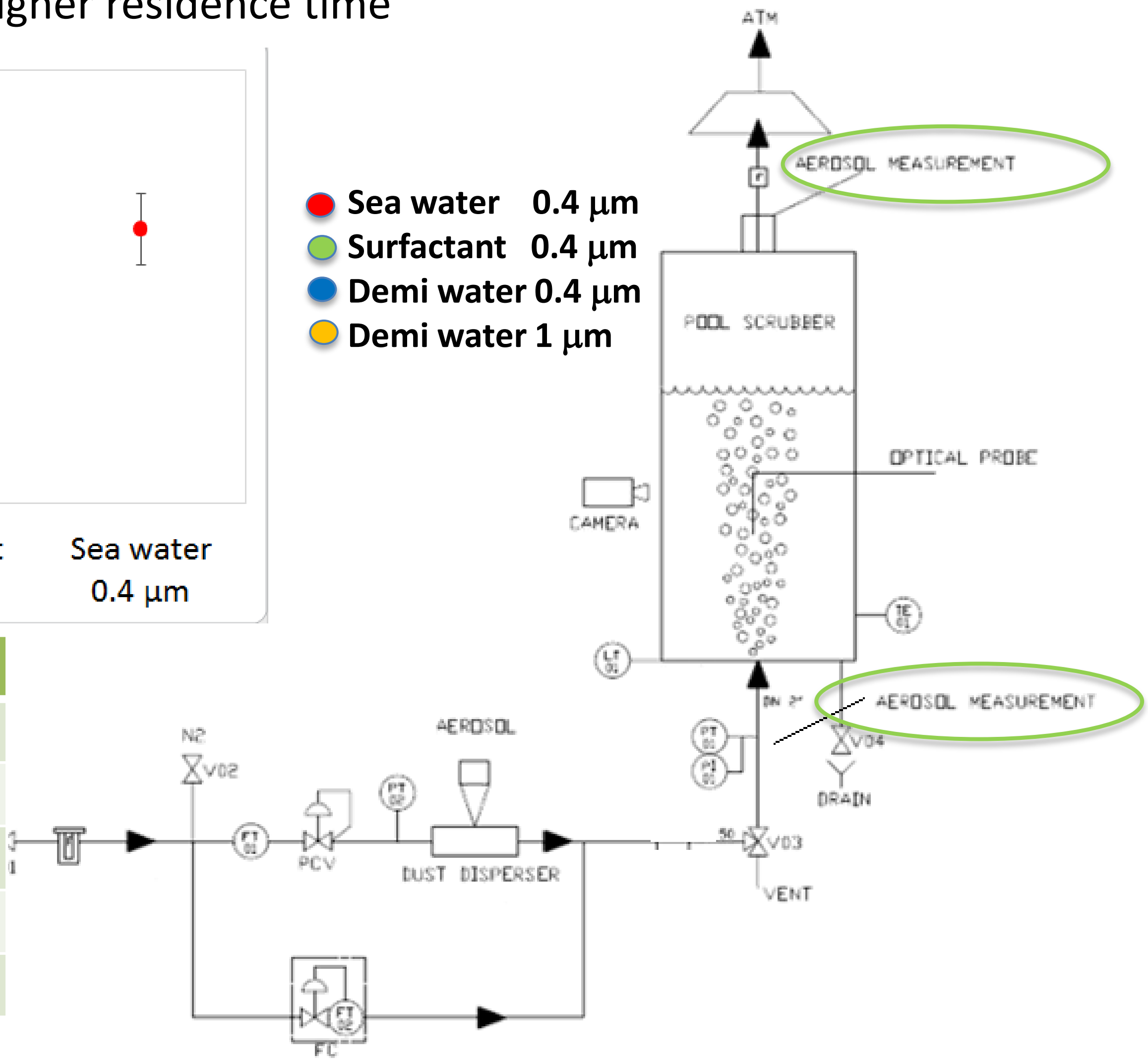
Liquid phase	Demineralized water	Seawater	Demi + Triton X-100
Density [kg/m^3]	1000	1025	1000
Surface tension [N/m]	0.072	0.072	0.036
Viscosity [mPl]	1.001	1.04	0.99
pH	7	8.2	6.1

Bubble velocity at injection zone depends even on bubble size distribution

Higher surface due to smaller bubbles size
Higher residence time

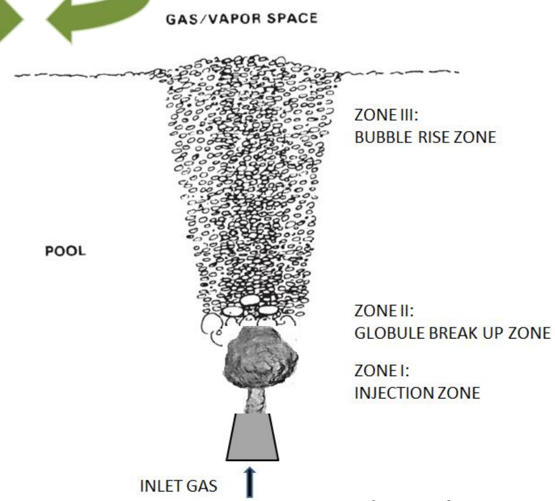
1 m pool





Liquid	Gas mass flow rate	Aerosol size	
		0.4 µm	1 µm
Demi	18 kg/h	X	X
	24 kg/h	X	X
Surfactant	18 kg/h	X	
Sea water	18 kg/h	X	

WP 3.1 - Model



Model based on ECART code
(Battelle experiment and Sparc code)

HYPOTESIS:

- Thermal equilibrium gas-water
- Single bubble evolution
- Break-up in two bubbles
- No coalescence
- DF_{Jet} for the first bubble

OUTPUT:

- Bubbles size
- DF

Decontamination Factor $DF = DF_{Jet} * DF_{Rise}$

a three-phase hydrodynamics
(bubble, liquid phase, droplets)

The phenomenons involved in the droplet capture of aerosol are the inertial impaction, interception, Brownian diffusion, thermophoresis, diffusiophoresis.

→ High spray system model

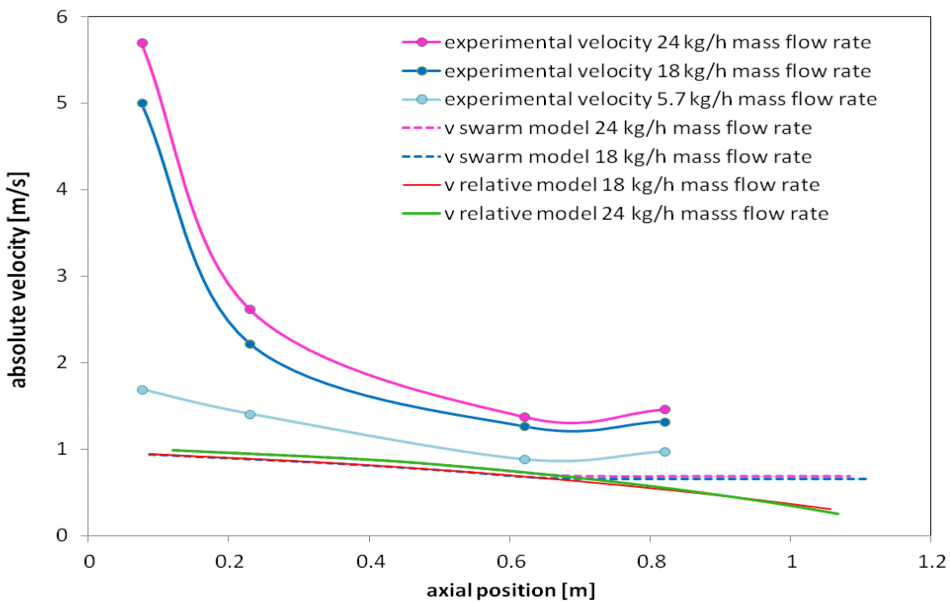
DF_{Jet} is evaluated with DF measures at 40 cm

two-phase hydrodynamics
(bubble, liquid phase)

Aerosol particles are removed due to particles movement towards the surface of the bubble (mechanisms of gravity settling, centrifugal impaction, Brownian diffusion, Thermophoresis, diffusiophoresis)

WP 3.1 – Model: open issues

Swarm velocity



Swarm velocity is underestimated

↓

overestimated rise time

↓

overestimated DF

The rising velocity of bubble swarms was confirmed as a key parameter that should be upgraded.

DIfferent liquid phase

- water with surfactant: model value near to experimental data
- sea water: We equal to that in demi water but different behaviour

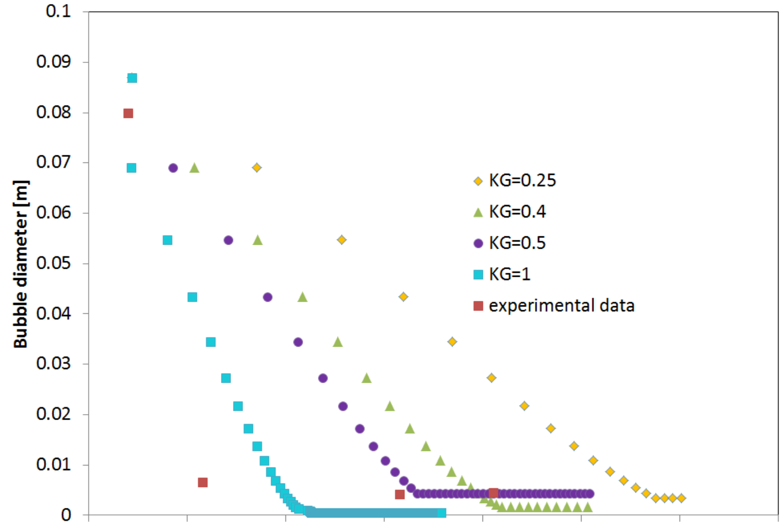
→ Coalescence and bubble number density

Bubble break up

Break up rate $$\frac{1}{t_b} = Kg(\tau_t - \tau_s)$$

τ_t **deformation stress**

τ_S **surface restoring pressure**

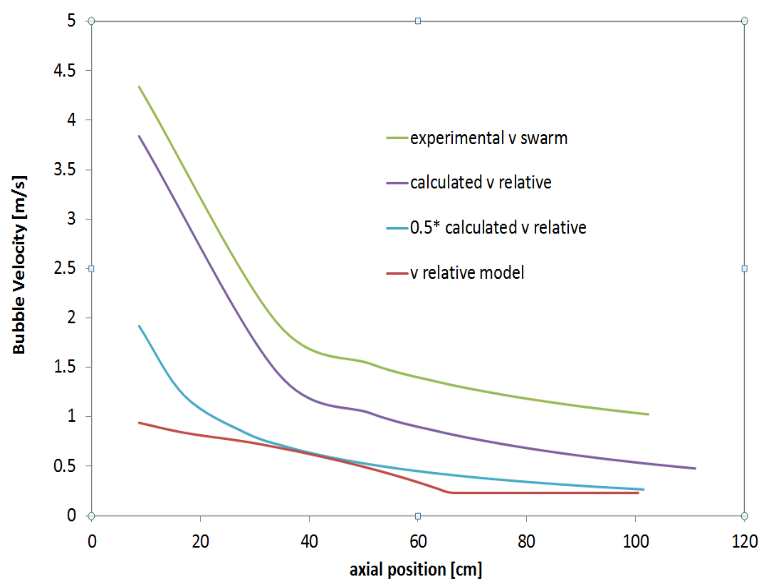


Hypotesis for jet regime:

Break-up in two bubbles

Bubble relative velocity

centrifugal impaction $\propto v^2_{rel}\, v_{set}$



CONCLUSIONS

- The local void distribution elaboration gives a good description of bubbles sizes
- in bare pool in jet regime in the injection zone a three-phase hydrodynamics model (bubble, liquid phase, droplets) and in the rise zone a two-phase hydrodynamics model (bubble, liquid phase) should be used
- **the rising velocity of bubble swarms was confirmed as a key parameter that should be upgraded**.
- higher decontamination is measured in sea water and water with surfactant than in demineralized water due to an increase of contact surface between the liquid and the gas phase and different residence time in pool

OPEN ISSUES

- sea water behaviour cannot be explain only with break up condition on We number
- the churn turbulent formation is fragmented in bubbles just after the injection zone: multiple break up ???
- Bubble number density and coalescence ??

Thanks for your attention

SCRUPOS Facility:
SCRUbbing by POol and Spray
(Layout Pool Scrubbing)