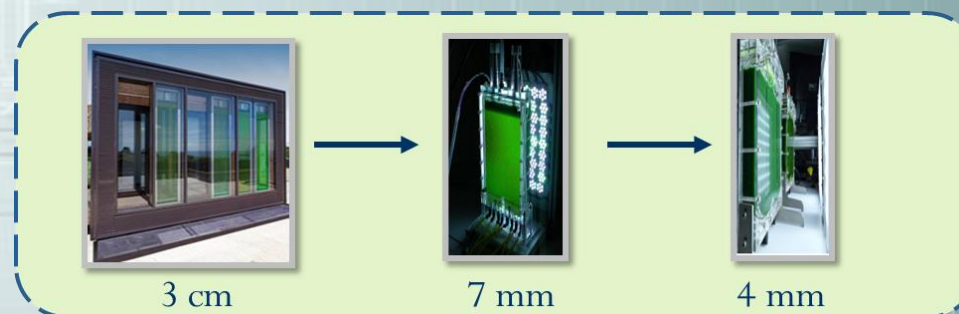


Thin gap bubble column with a non-Newtonian liquid phase: study of the hydrodynamics and gas-liquid mass transfer



Presented By :

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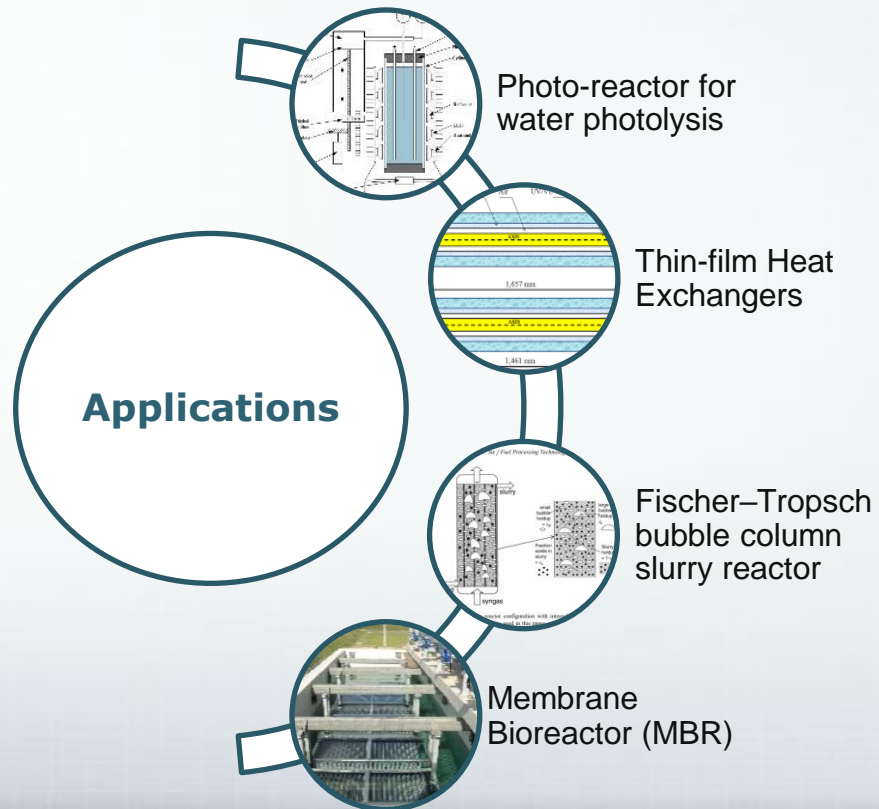
OUTLINES

- 1 Introduction
- 2 Context & objectives of the project
- 3 Material and methodology
- 4 Results and discussion
- 5 Conclusion & perspectives

1- Introduction

- Bubble column & advantages
- Design & scale up (*understanding complex hydrodynamics*)
- Thin gap bubble column (*millimetric thickness*)

General



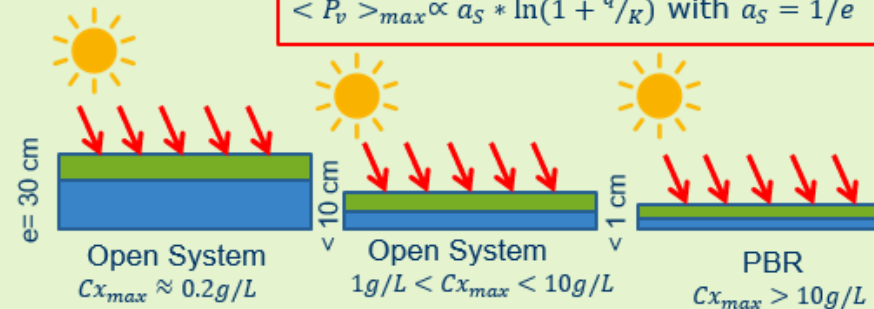
Specific

Photobioreactor (PBR) for microalgae culture

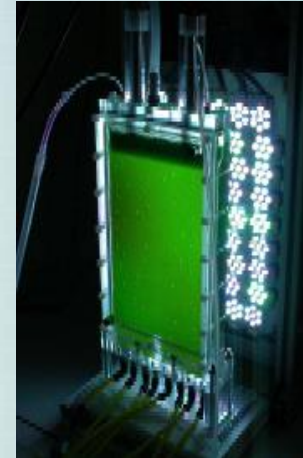
Solution = Intensification of culture growing conditions :

- cell concentration
- thickness of PBR

$$\langle P_v \rangle_{\max} \propto a_S * \ln(1 + q/K) \text{ with } a_S = 1/e$$



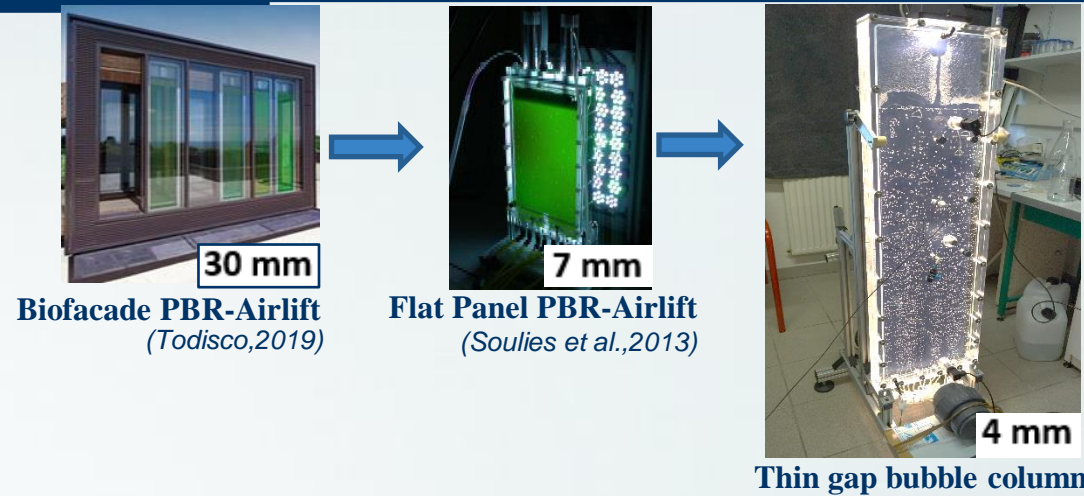
- costs (production, agitation, harvest, etc.)
- productivity



Flat Panel PBR (Airlift)
25 cm × 15 cm × 7 mm
(Soulies et al., 2013)

2- Context & objectives of the project

Photobioreactor Intensification



GOAL

Hydrodynamics and gas liquid mass transfer in thin gap bubble column with non-Newtonian liquid phase.

Such as: Microalgae culture at high concentration *(Soulies et al., 2013)*

Objectives

Characterization of thin gap bubble column (4 mm) with different non-Newtonian **model fluids** and sparging conditions.

- ✓ Effect of Confinement
- ✓ Effect of bubble size at sparger
- ✓ Effect of rheological properties of fluids

Outcomes:

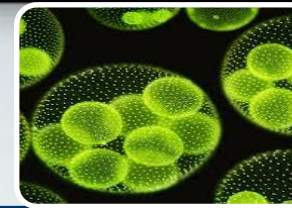
Global characterization :

- Gas Holdup
- Flow Regime Transition
- Mixing Time
- Gas Liquid Mass Transfer Coefficient

Local characterization :

- Gas Phase (Shadowgraphy)
- Liquid Phase (PIV)

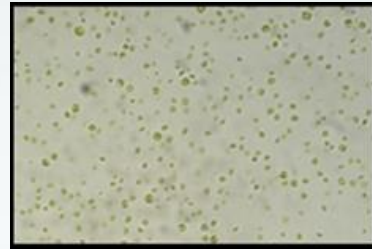
3-Materials and Methodology



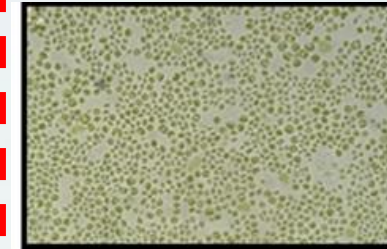
RHEOLOGICAL BEHAVIOUR OF *CHLORELLA VULGARIS* AT HIGH CONCENTRATION

3.1 Methodology to **mimic** biological culture.

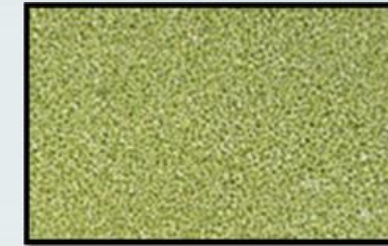
- ❖ The rheological behaviour switches from Newtonian to non Newtonian, when microalgae cell concentration increases. (Souliès et al., 2013).
- ❖ For *Chlorella vulgaris*, three distinct rheological behaviour are observed.



Newtonian (N)
 $C_x < 30 \text{ g/L}$



Shear Thinning (ST)
 $30 \text{ g/L} < C_x < 65 \text{ g/L}$



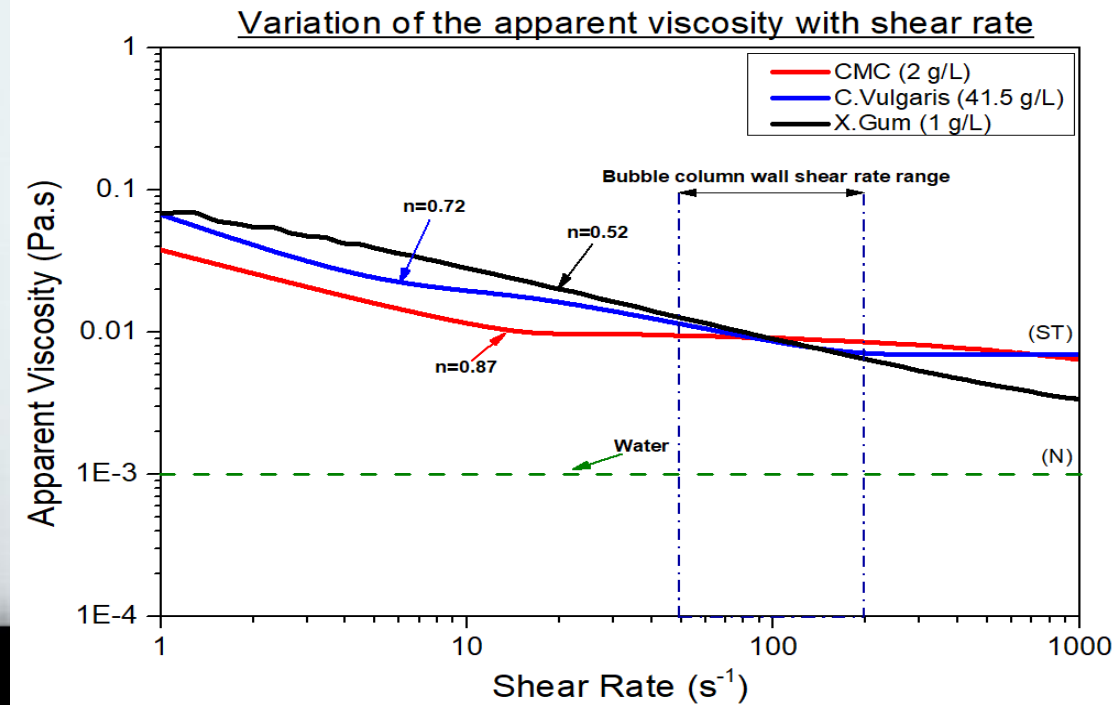
Yield Stress (YS)
 $C_x > 65 \text{ g/L}$

- ❖ Microalgae culture data of (Souliès et al., 2013) at shear thinning behaviour (41.5g/l) compared to the rheological data of CMC and XG determined by Rheometer (PAAR Physica® MCR500).

- ❖ Relationship between viscosity (μ_{eff}) and shear rate $\gamma \text{ (s}^{-1}\text{)}$:

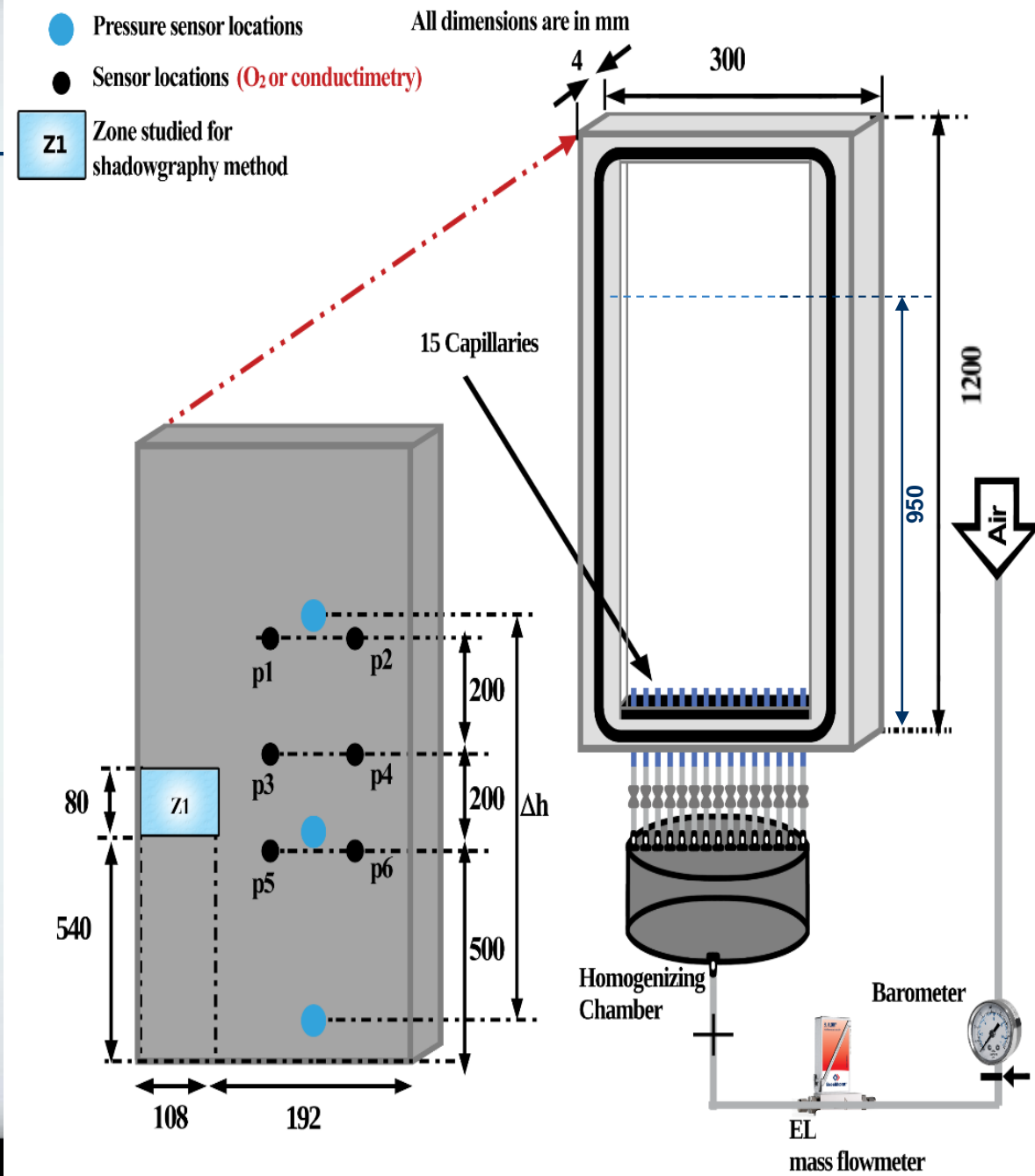
$$\mu_{eff} = K \cdot \gamma^{n-1} \text{ (Power Law Model)}$$

K is the flow consistency index and **n** is flow behaviour index.



3.2 Experimental Setup

- Thin-gap bubble column (4 mm * 300 mm * 1200 mm).
- Gas sparging with 15 capillaries.
- Four capillary diameters 0.254, 0.508, 0.762 and 1.016 mm.
- Liquid height 950 mm corresponding to liquid volume 1.17 litre.
- Gas flowrate is adjusted using EL mass flowmeter.
- 2 pressure sensors (KELLER PR25).
- p1 for conductivity and p5 for O_2 sensors.



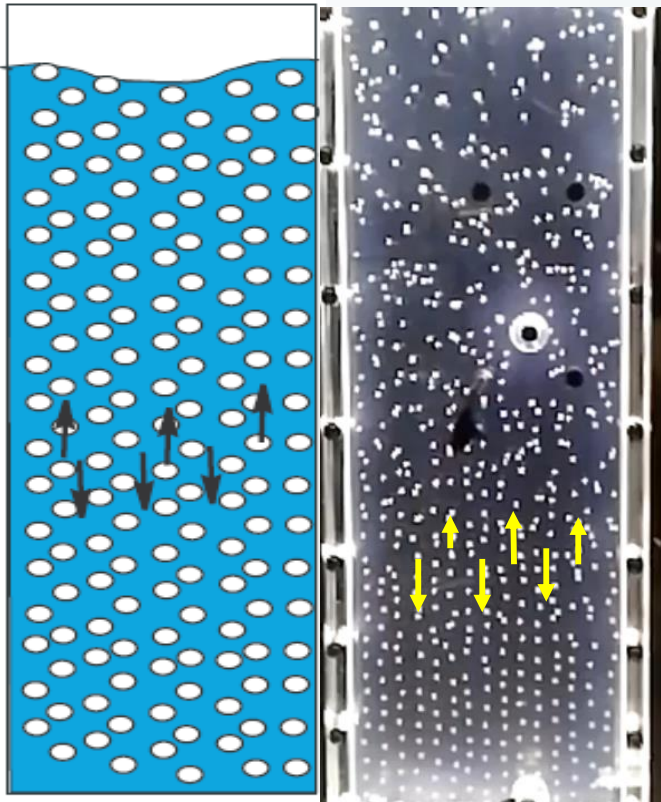
3.3 Hydrodynamics in a bubble column

Bubble Column: allows the culture mixing and ensures the gas-liquid transfers that is necessary for the growth of microorganisms.

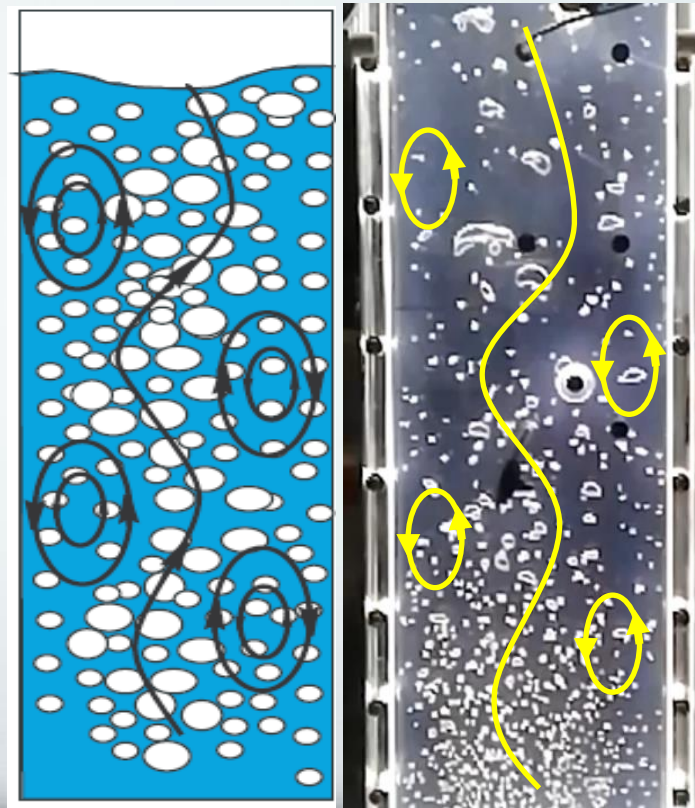
3 flow regimes:

Preferred regime for microalgae culture

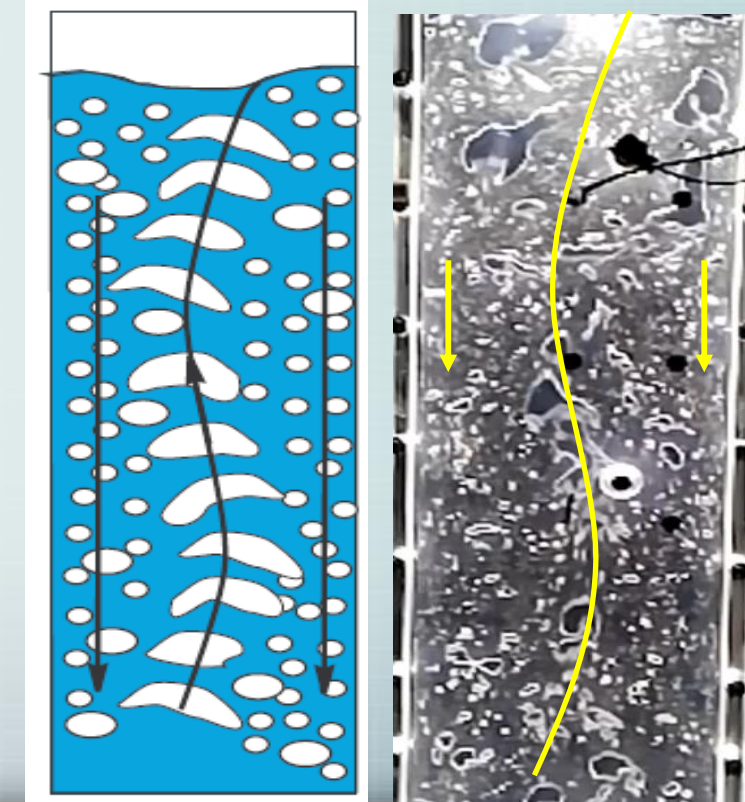
homogeneous



transition



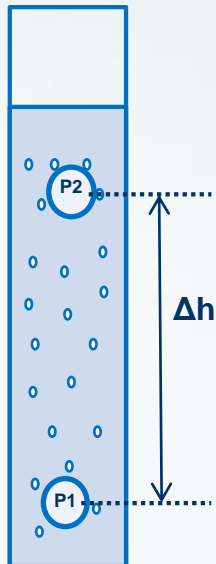
heterogeneous



3.4 Measurement Techniques

Gas holdup measurement and characterization of flow regimes (Results of Tap water-0.254 mm capillaries)

By measuring the differential pressure

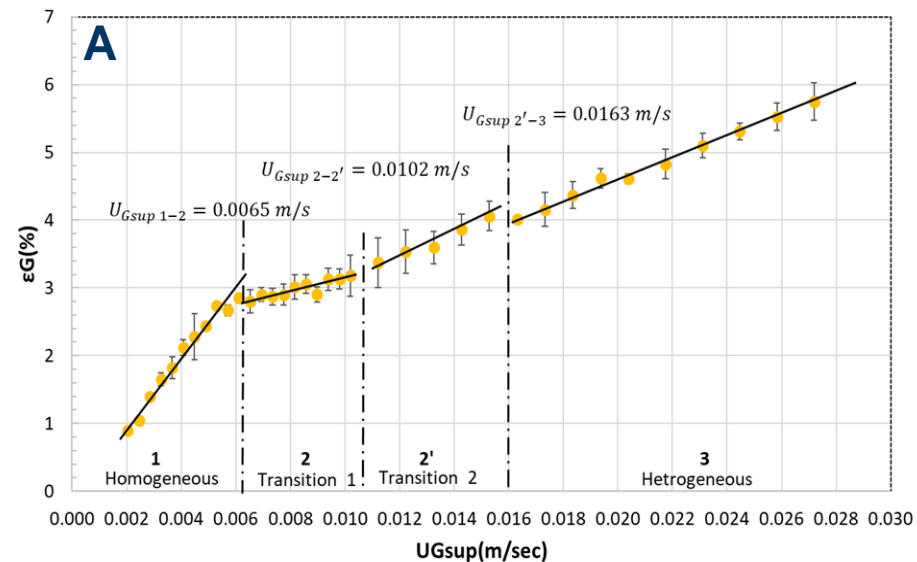


$$\epsilon_G = 1 - \frac{\Delta P}{\rho_L g \Delta h}$$

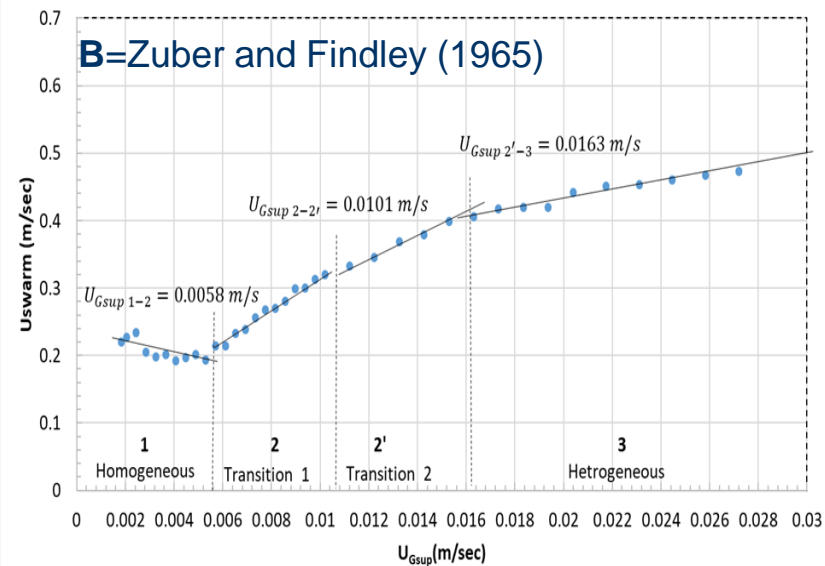
Methods

$\epsilon_G = f(U_{Gsup})$	A	$\epsilon_G = 1 - \frac{\Delta P}{\rho_L g \Delta h}$
$U_{swarm} = f(U_{Gsup})$	B	$U_{swarm} = \frac{U_{Gsup}}{\epsilon_G}$
$\langle j_{GL} \rangle = f(\epsilon_G)$	C	$\langle j_{GL} \rangle = U_{Gsup} * (1 - \epsilon_G)$

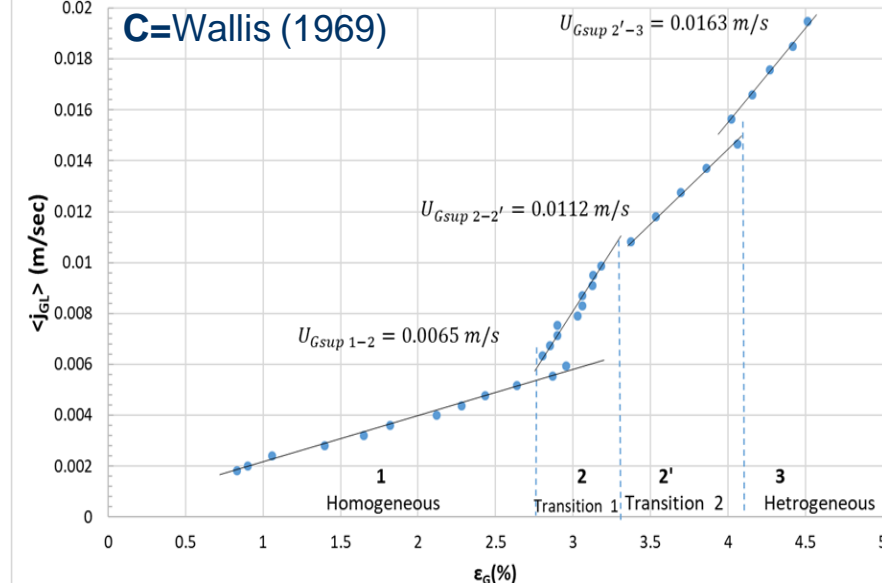
Gas Holdup vs Superficial Gas Velocity



Uswarm vs Superficial Gas Velocity



$\langle j_{GL} \rangle$ vs Gas holdup(%)

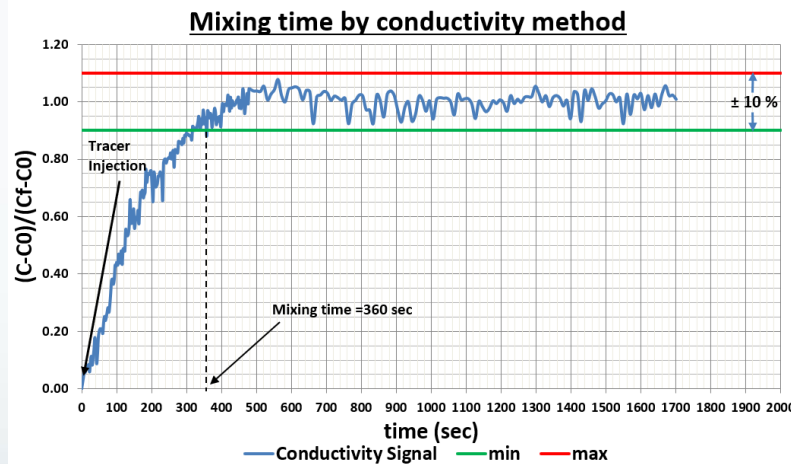
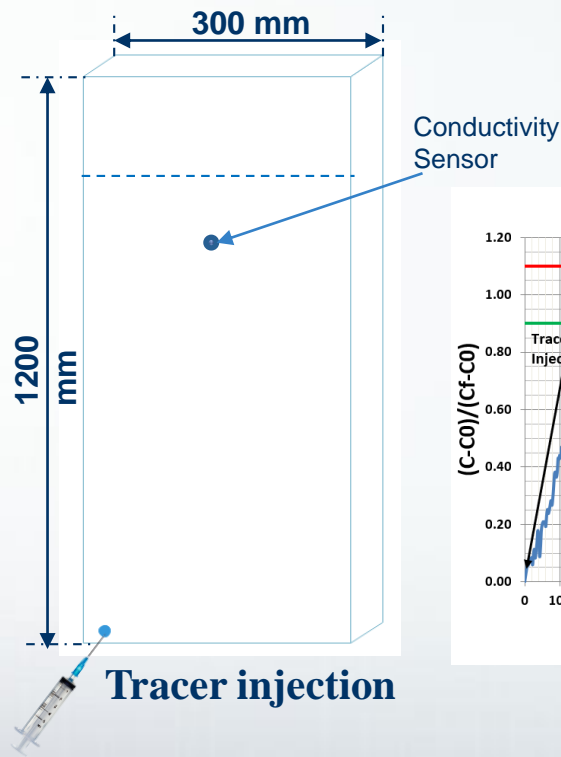


3.4

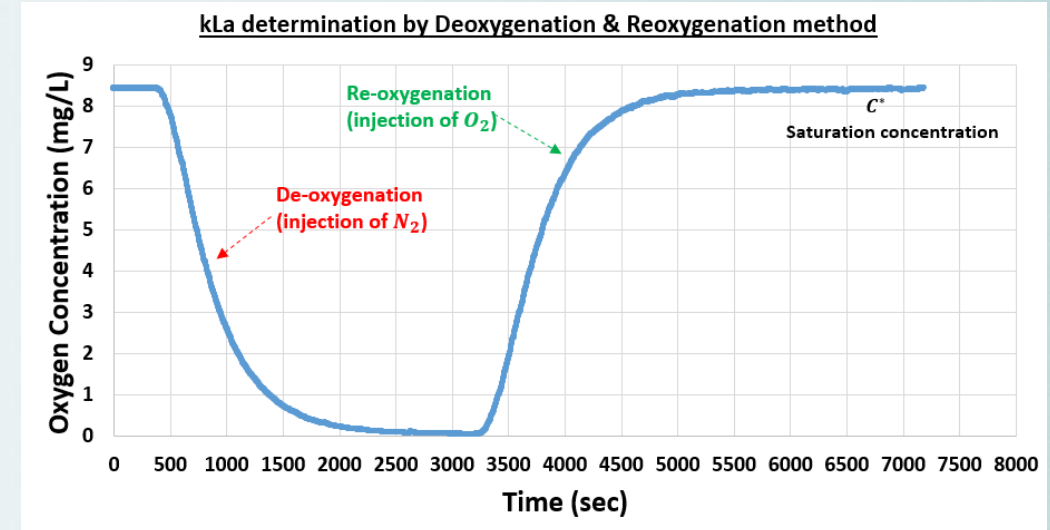
Measurement Techniques....

Conductivity Method → Mixing Time (t_m)

- Tracer injection of 2 mL of a NaCl solution at 200 g/L .
- Experiments triplicated for water and repeated 5 times for non-Newtonian fluids.

**Mixing Time determination****Deoxygenation - Reoxygenation Method → kLa**

- Deoxygenation of the reactor by aeration with N_2 sparging.
- O_2 concentration as a f (t) during the deoxygenation & reoxygenation step. The slope of Eq: 2 gives the value of ' kLa '.

**Deoxygenation-Reoxygenation Curves**

linearization

Perfectly mixed liquid phase &
constant gas composition

$$\frac{dC}{dt} = kLa (C^* - C(t)) \quad \text{Eq:1}$$

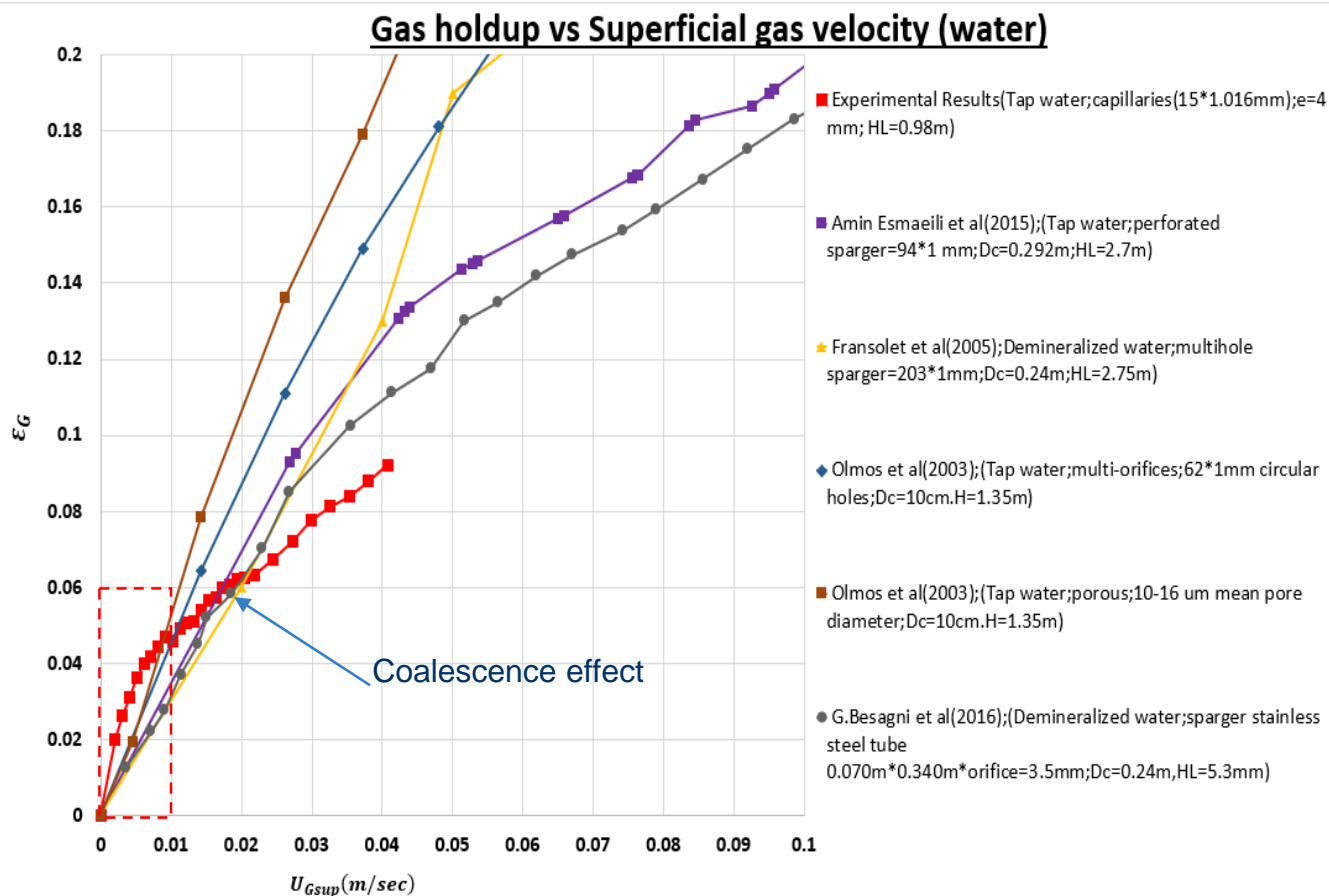
$C^* = O_2$ saturation concentration

$$\ln \left(\frac{C^* - C(t)}{C^* - C(t=0)} \right) = kLa \cdot t \quad \text{Eq:2}$$

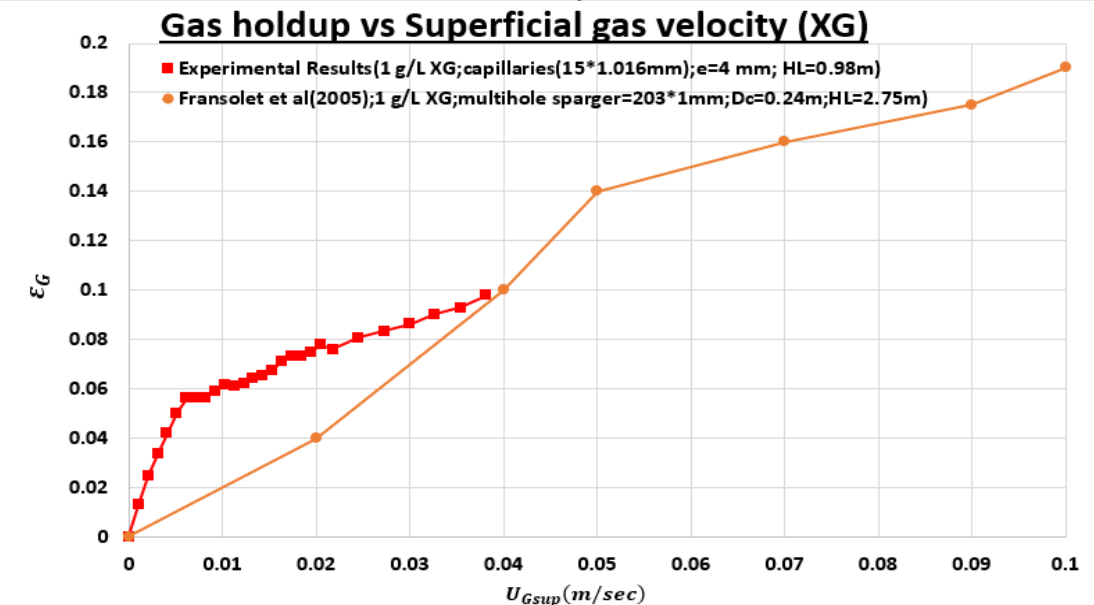
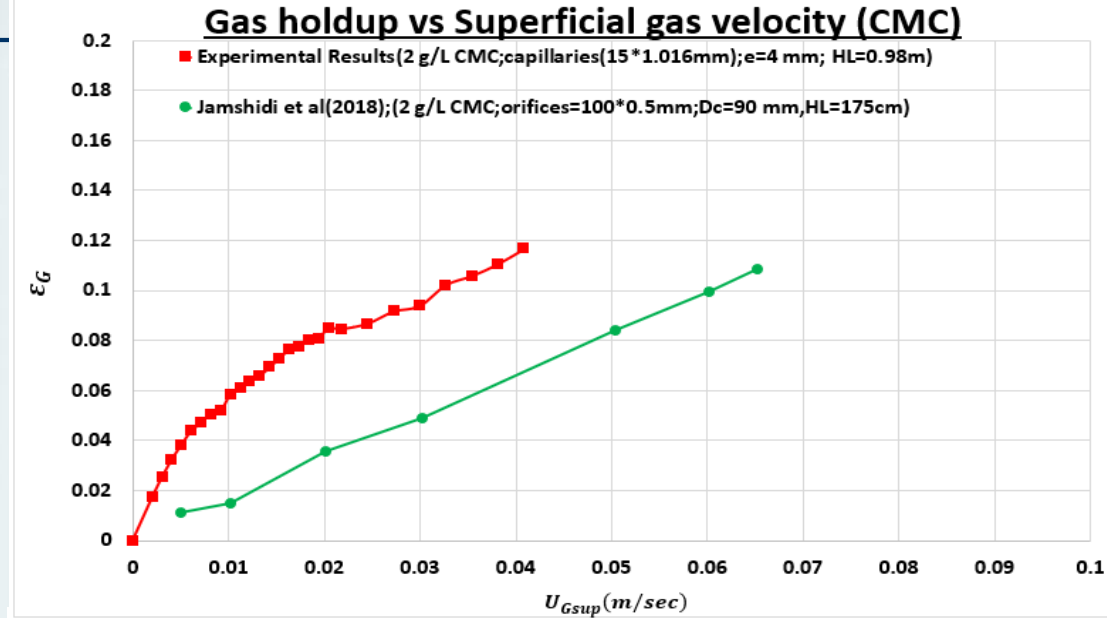
4. Results and Discussion

4.1 Influence of confinement on gas holdup (ε_G)

Water : homogeneous regime, ε_G is slightly greater than in conventional BCs.



CMC & XG : ε_G is higher than in conventional BCs for all three regimes



4.2

Influence of fluid

Fluid

Average Regime transition

by three methods

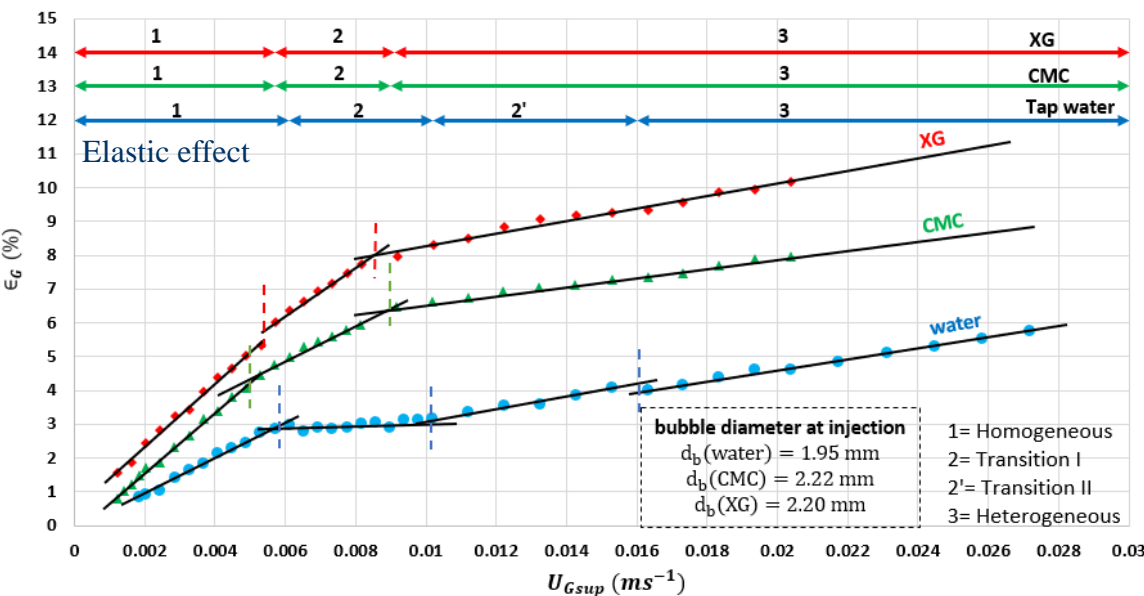
 $U_{Gsup\ 1-2} (m.s^{-1})$

(Homo to transition)

 $U_{Gsup\ 2-3} (m.s^{-1})$

(Transition to hetero)

Gas holdup vs Superficial gas velocity (0.254 mm capillary)



p)

0.0062

0.0162

isup)

0.0057

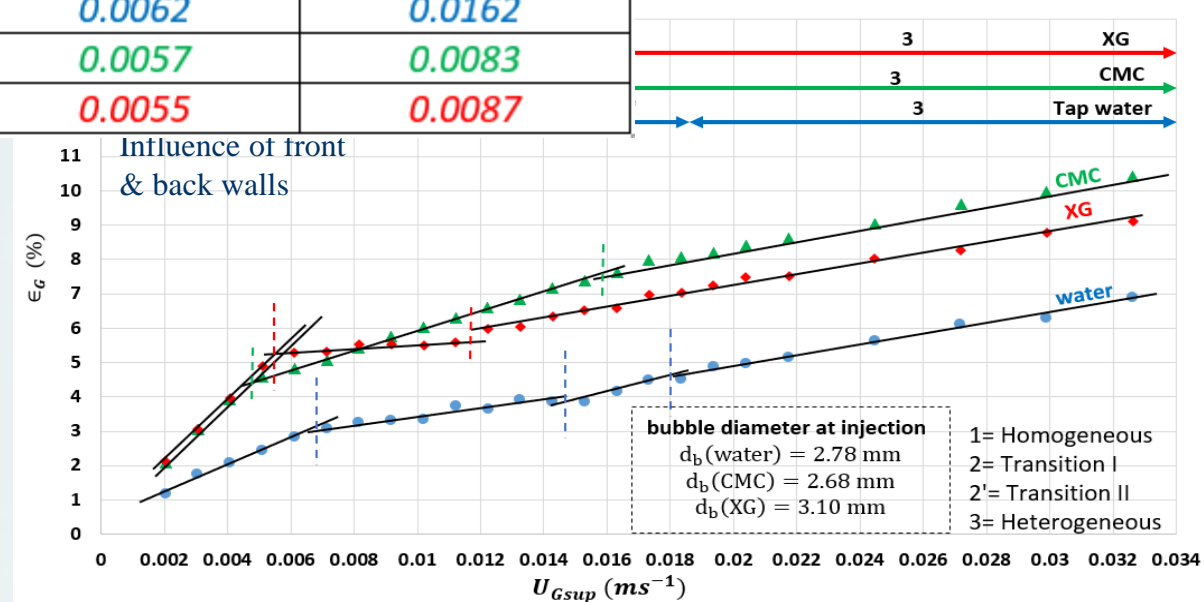
0.0083

G)

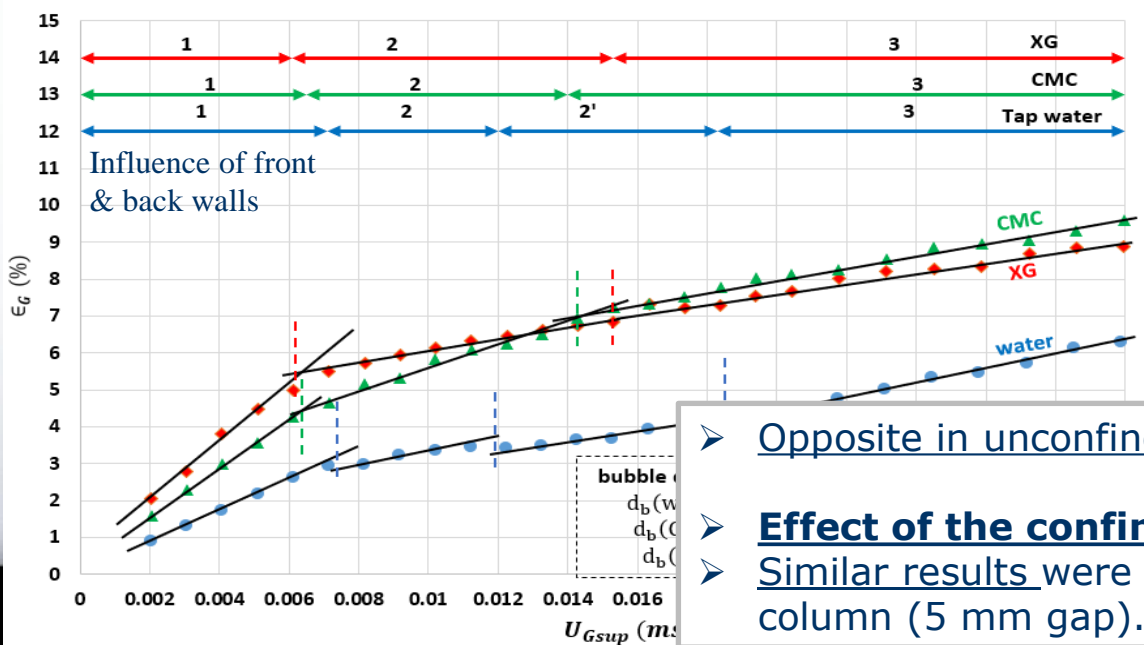
0.0055

0.0087

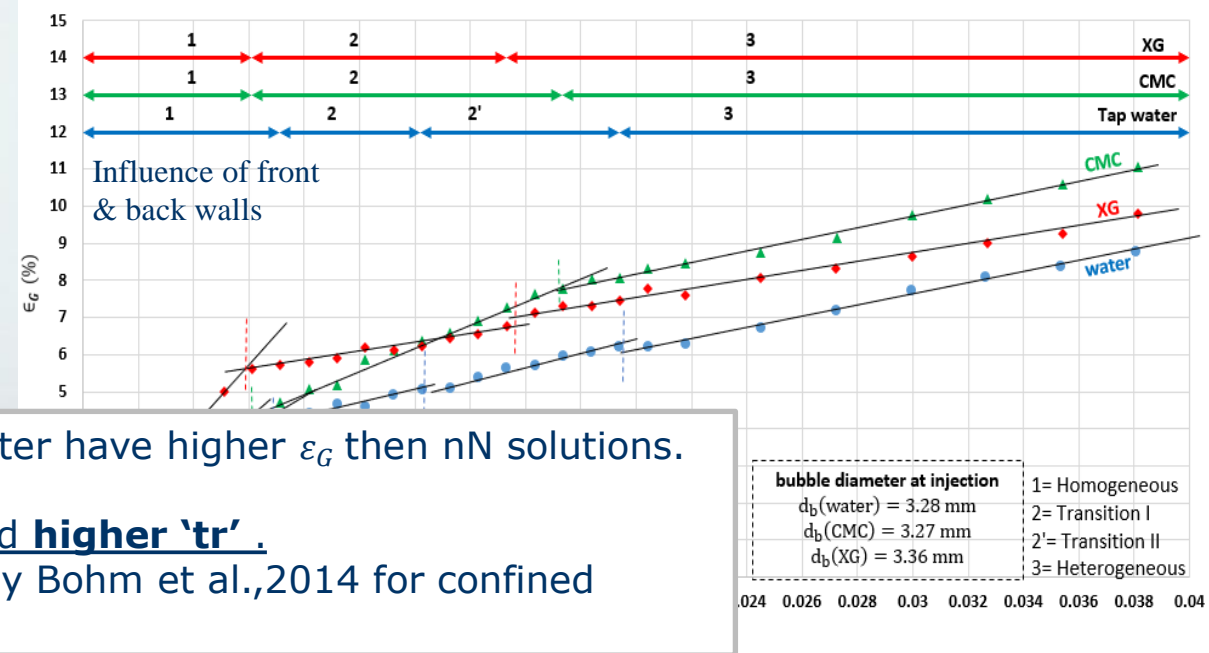
Gas holdup vs Superficial gas velocity (0.508 mm capillary)



Gas Holdup vs Superficial gas velocity (0.762 mm capillary)



Gas Holdup vs Superficial gas velocity (1.016 mm capillary)



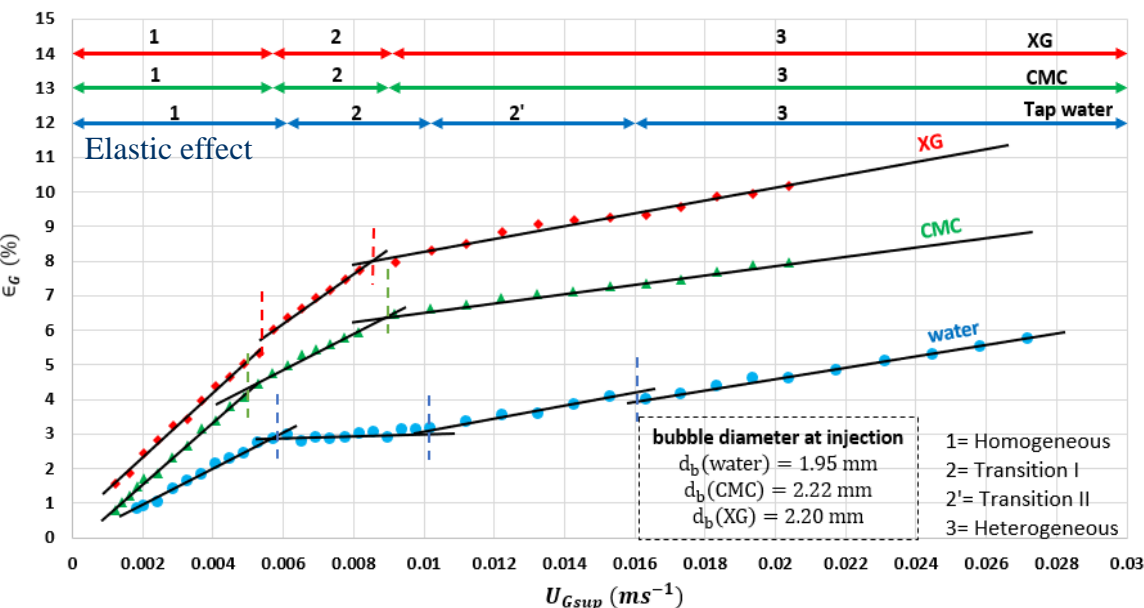
➤ Opposite in unconfined BC : water have higher ε_G then nN solutions.

➤ **Effect of the confinement and higher 'tr'.**

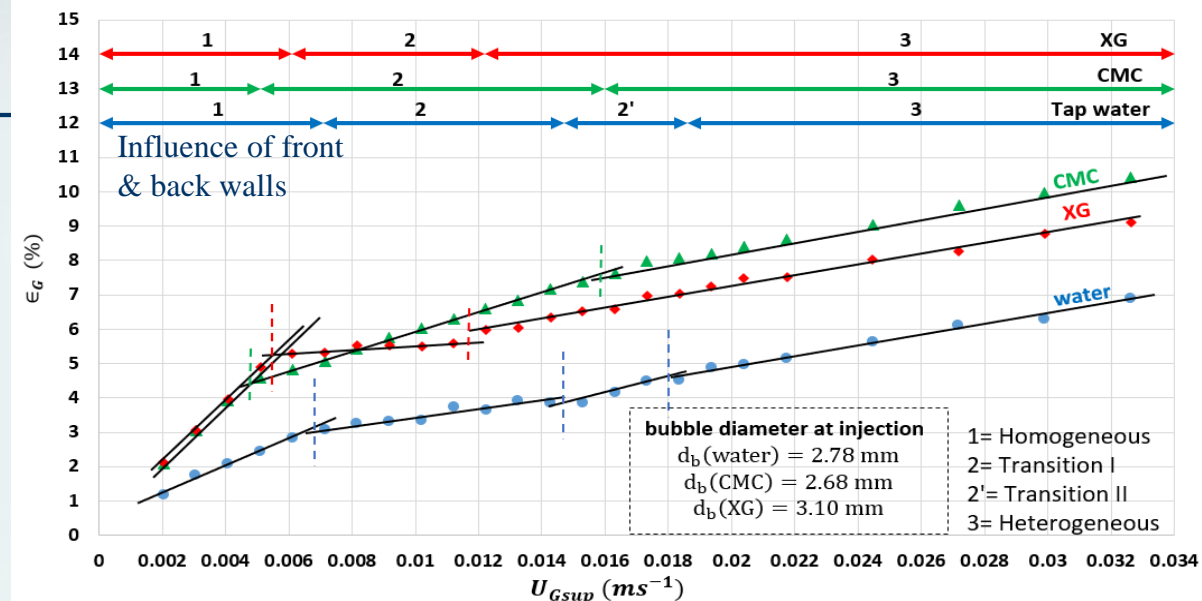
➤ Similar results were observed by Bohm et al.,2014 for confined column (5 mm gap).

4.2 Influence of fluid rheology & bubble size at sparger on ϵ_G

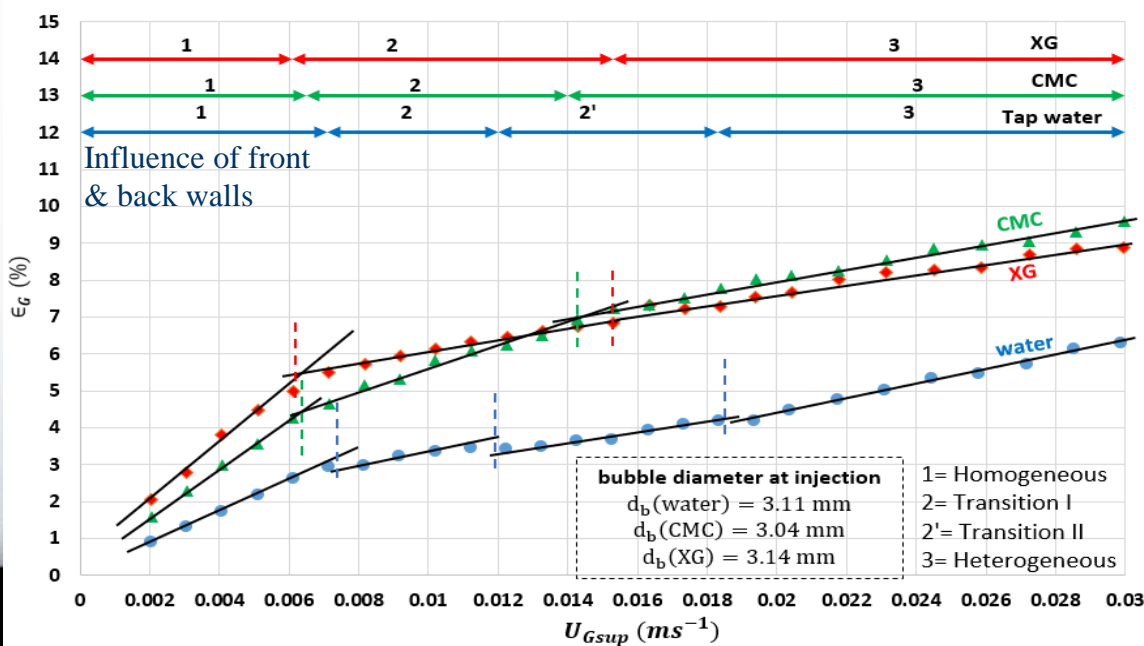
Gas holdup vs Superficial gas velocity (0.254 mm capillary)



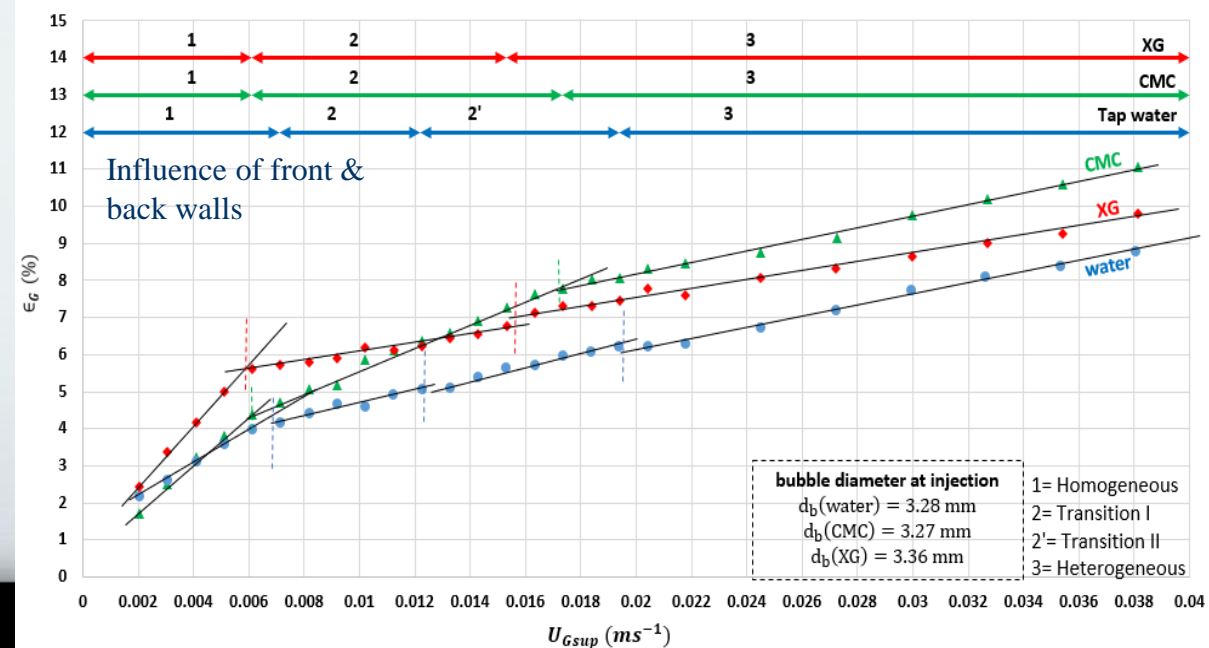
Gas Holdup vs Superficial gas velocity (0.508 mm capillary)



Gas Holdup vs Superficial gas velocity (0.762 mm capillary)



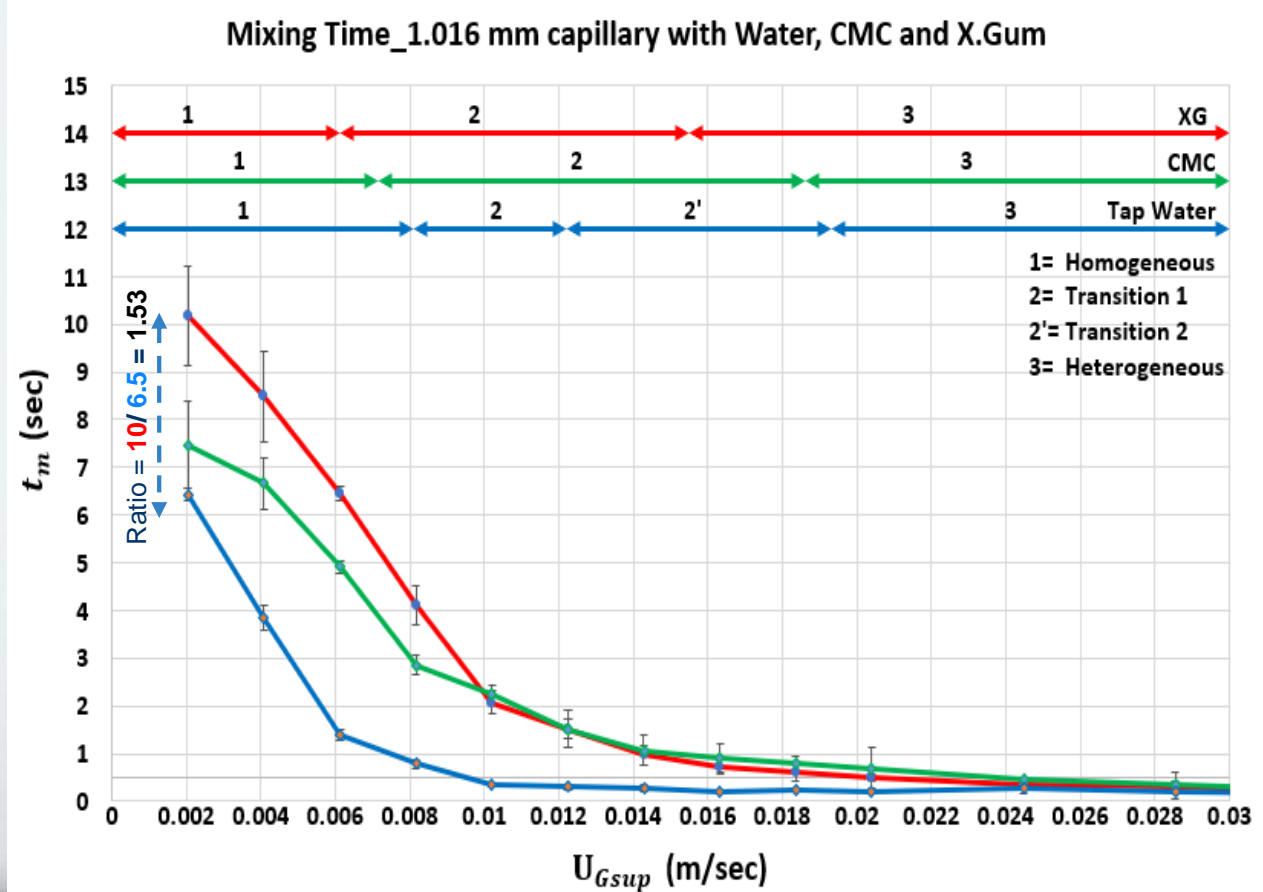
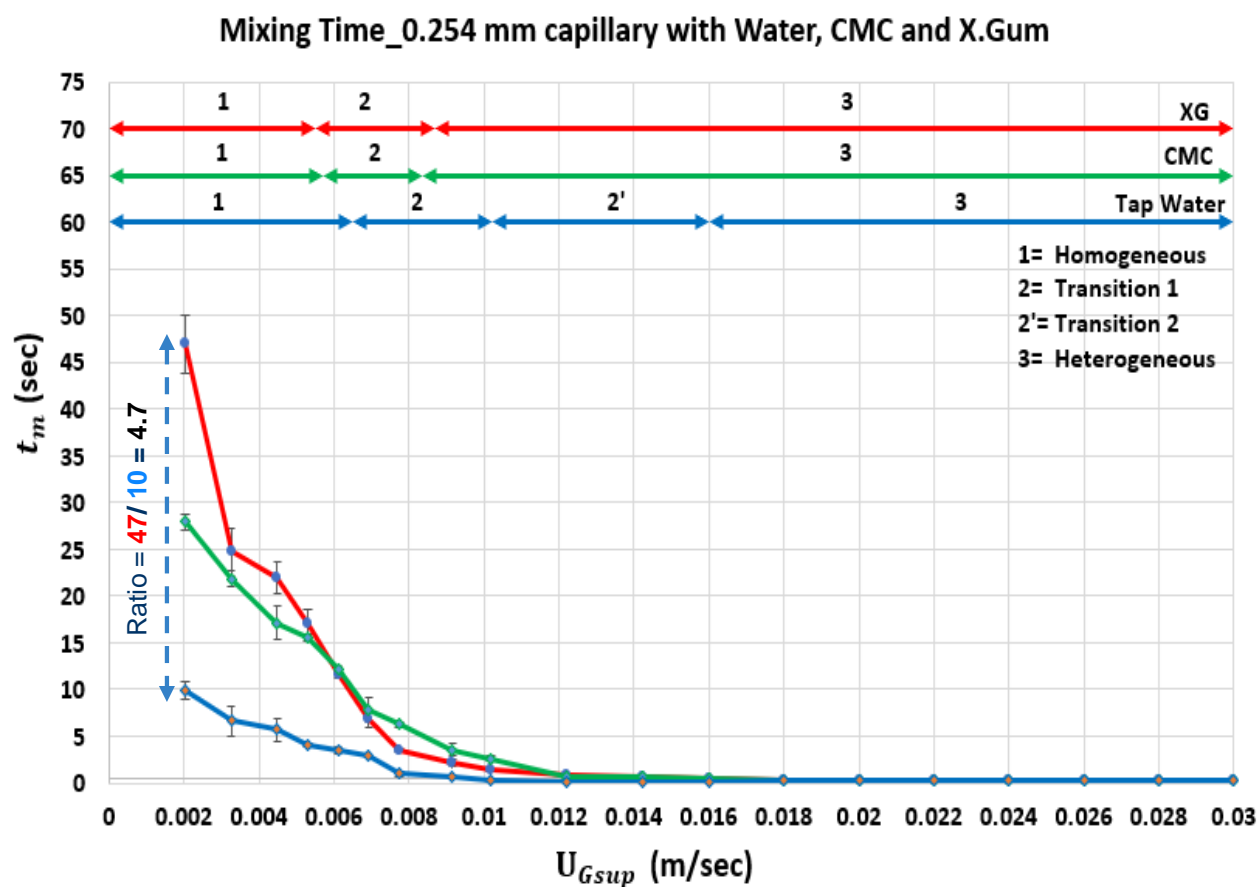
Gas Holdup vs Superficial gas velocity (1.016 mm capillary)



4.3 Influence of liquid rheology & bubble size at sparger on Mixing time (t_m)

- t_m \searrow with the $\nearrow U_{Gsup}$
- t_m \searrow with the $\nearrow d_{cap}$

- t_m in nN higher than water (*viscosity effect*), especially in homogeneous & transition regimes.
- The trajectory, fluctuations and the bubble shape in water is much different than nN fluids.



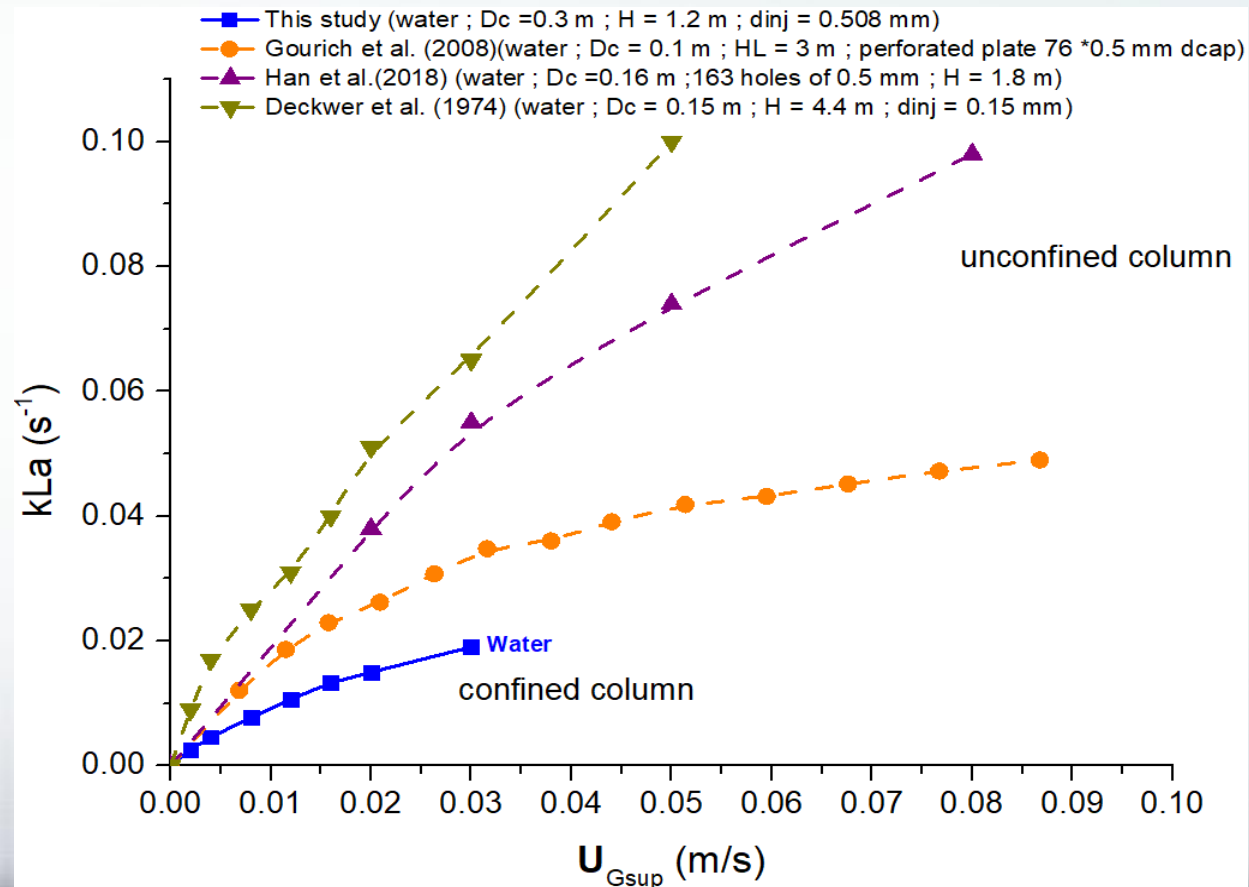
4.4

Influence of confinement on kLa

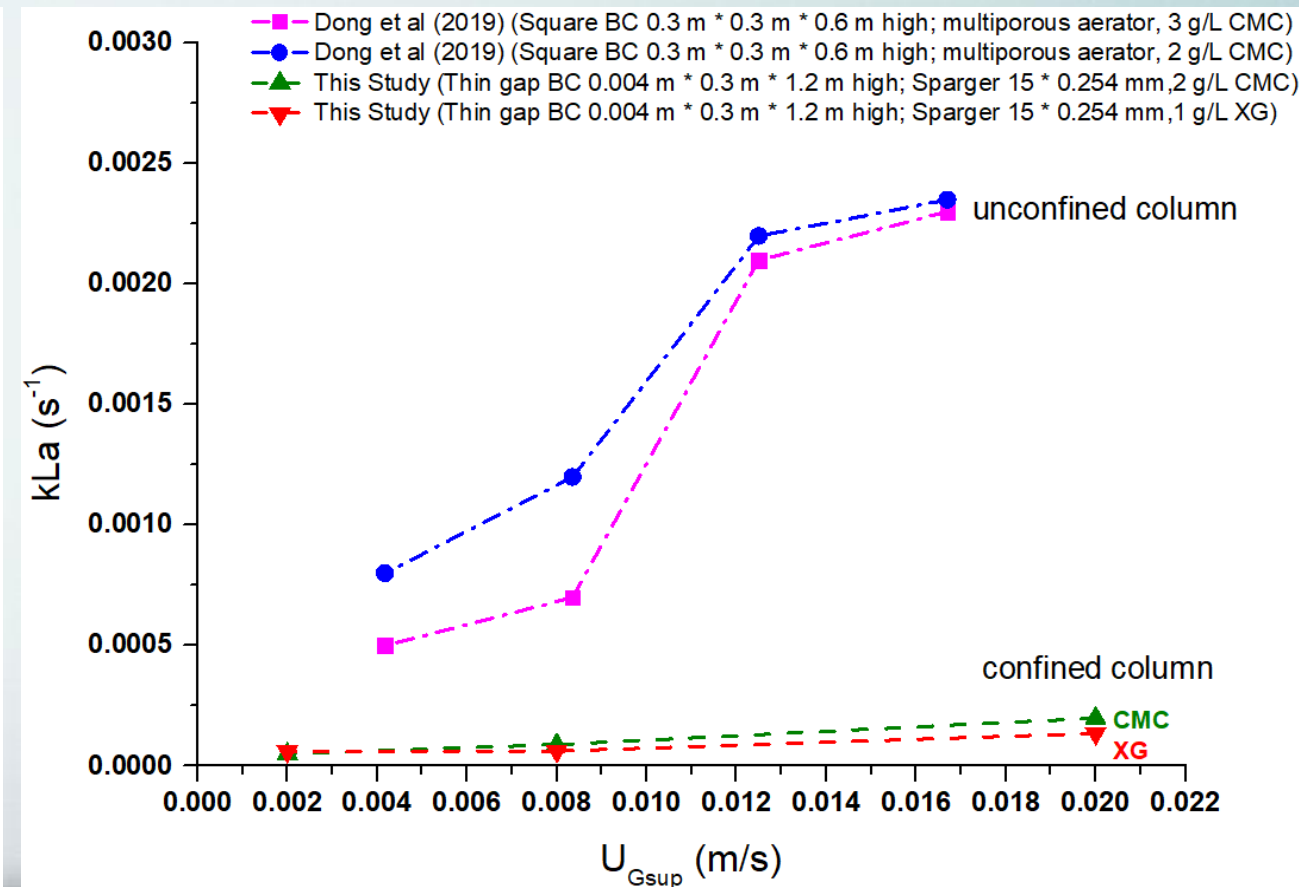
➤ Confined BC kLa results vs unconfined BC kLa results.

➤ The value of kLa lower then in conventional BCs. (Thobie et al.,2017 , for water and glycerol , same thickness)

Comparison of kLa (water) with kLa in infinite columns



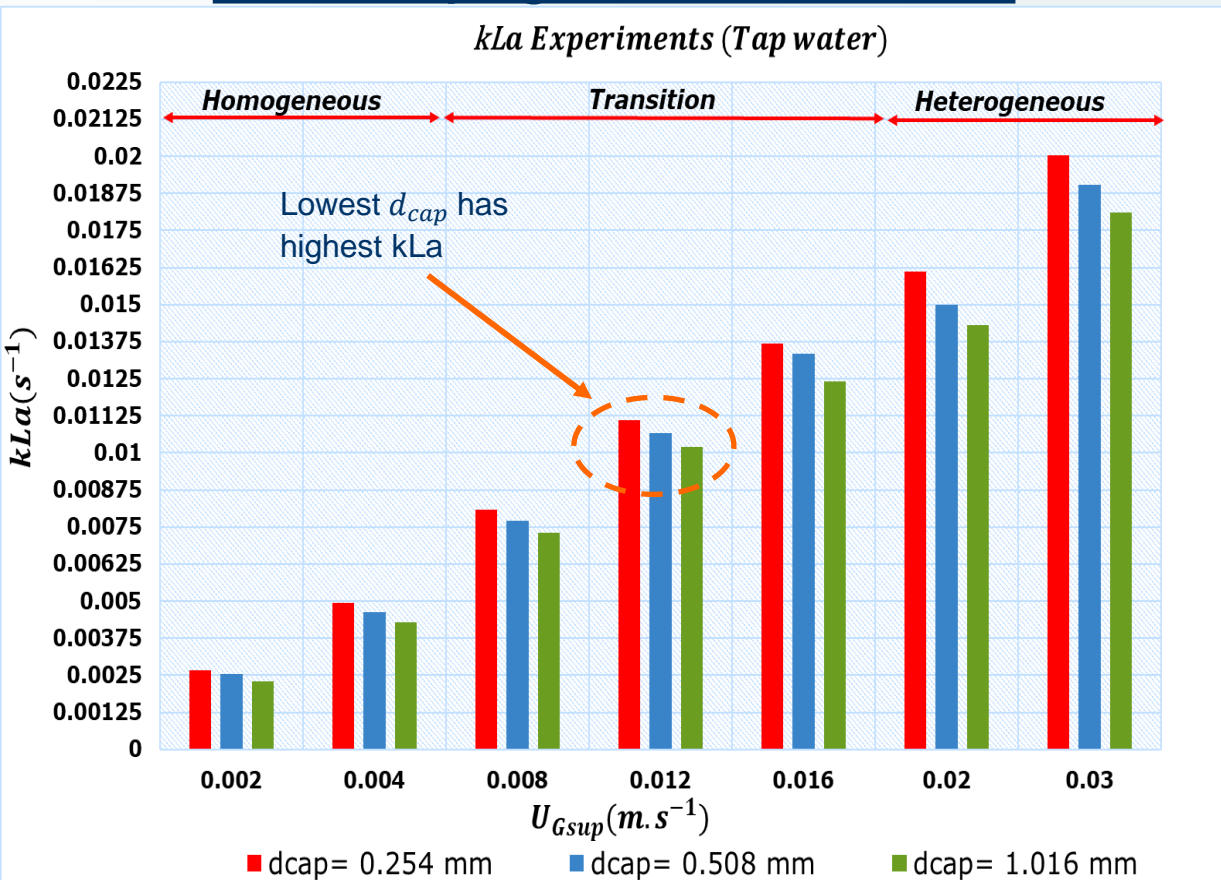
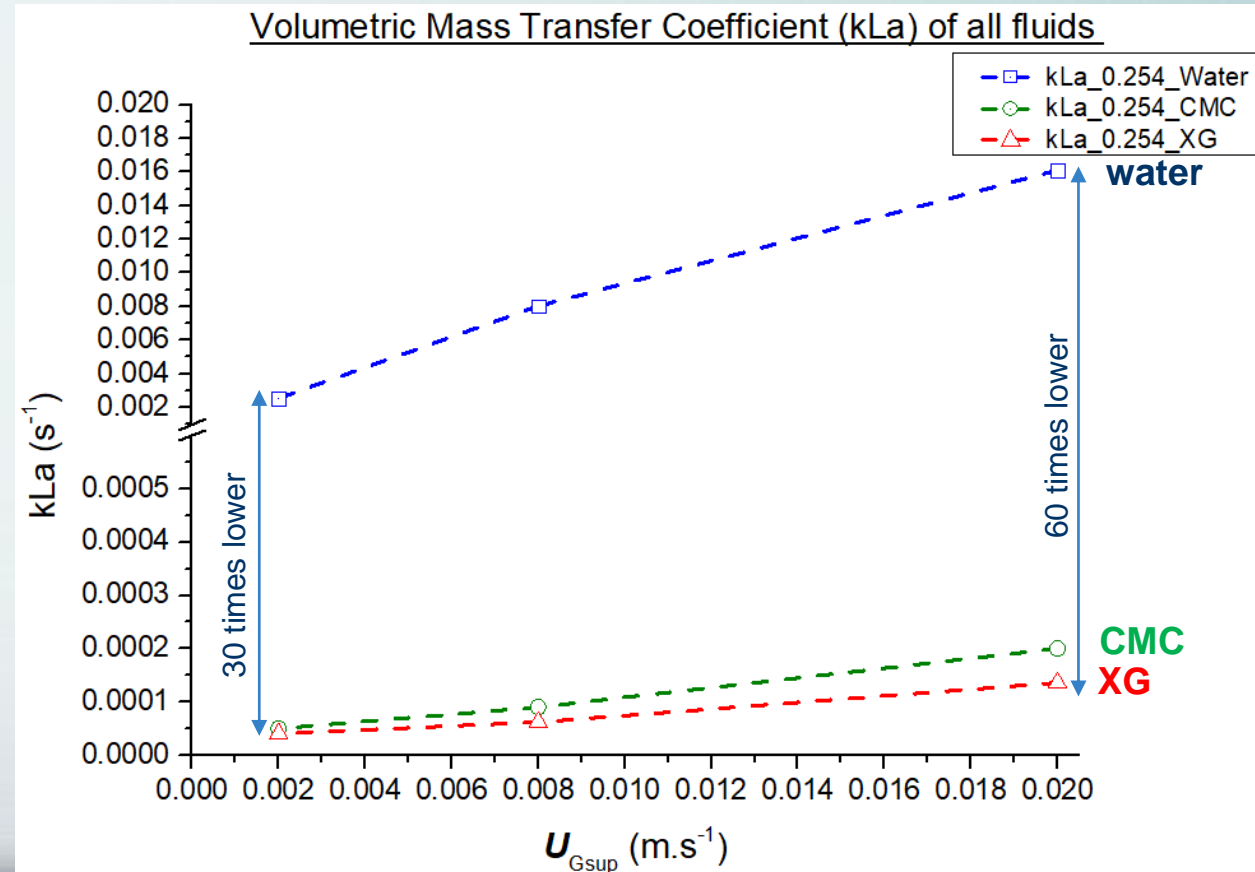
Comparison of kLa (CMC and XG) with kLa in infinite columns



4.5

Influence of fluid rheology and bubble size at sparger on kLa

- kLa \nearrow with the \nearrow U_{Gsup} .
- kLa \searrow with the \nearrow d_{cap} (due to interfacial area of bubbles, db and number of bubbles)
- kLa \searrow with the \nearrow μ_{fluid}
- kLa is much higher in Newtonian fluids (tap water) than in nN fluids.

Effect of sparger's diameter on kLa Effect of Rheological Properties on kLa 

5- Conclusion & Perspectives

GAS HOLDUP

- ε_G is more important in confined column.
- ε_G of nN liquids > Newtonian in confined column (*high residence time*)

REGIME TRANSITIONS

- The RT in confined column occur earlier compared to conventional BCs
- The RT for non-Newtonian liquids appear at lower U_{Gsup} than Newtonian. (*coalescence tendency*)

MIXING TIME

- t_m is higher in confined column than unconfined column.
- $t_m \downarrow$ with $U_{Gsup} \uparrow$ & $t_m \downarrow$ with $d_{cap} \uparrow$
- t_m in nN liquids is quite poor at low U_{Gsup} (*viscosity effect*)

GAS LIQUID MASS TRANSFER COEFFICIENT

- The value of kLa is lower in thin gap bubble column compared to conventional BCs.
- kLa is poor in nN fluids than in Newtonian (water).
- $kLa \uparrow$ with $d_{cap} \downarrow$ (due to 'a', 'db' and 'nb')

The local hydrodynamics characterization will be performed :

- ✓ Gaseous phase by shadowgraphy
- ✓ Liquid Phase by Particle image velocimetry (PIV)



Optimization of culture conditions:

- Flowrate, bubble diameter

Regime Transition visualization

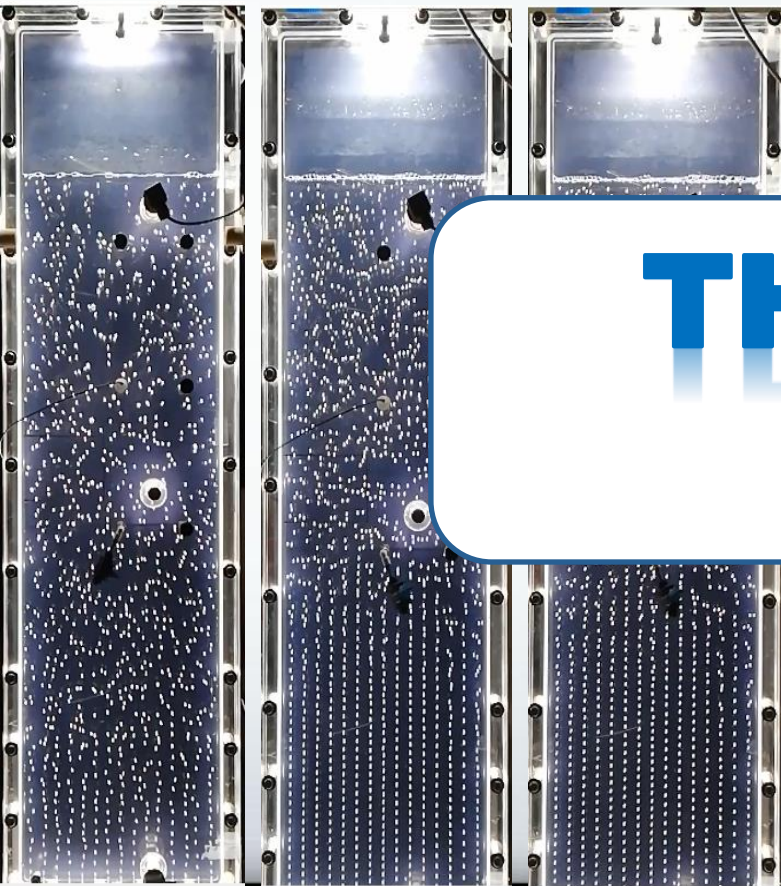
Homogeneous Regime

$$U_{Gsup} = 0.002 \text{ m/s}$$

Water

CMC

XG



Transition Regime

$$U_{Gsup} = 0.008 \text{ m/s}$$

Water

CMC

XG



Heterogeneous Regime

$$U_{Gsup} = 0.02 \text{ m/s}$$

Water

CMC

XG



**THANKS FOR YOUR
ATTENTION**

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