A microscopic look at the fouling mechanisms in dairy protein mixes by rheometry and microfluidics

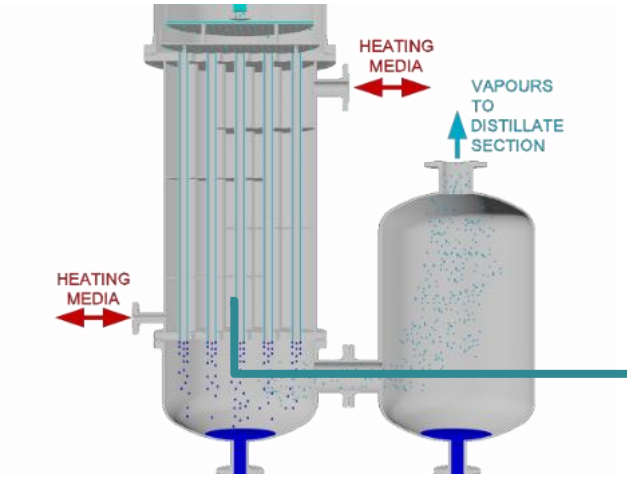
Margot Grostete, Romain Jeantet, Jeehyun Lee, Maude Jimenez, Luca Lanotte, Françoise Boissel, Gaëlle Tanguy, Salima Khelifaoui, Cécile Le Floch-Fouéré

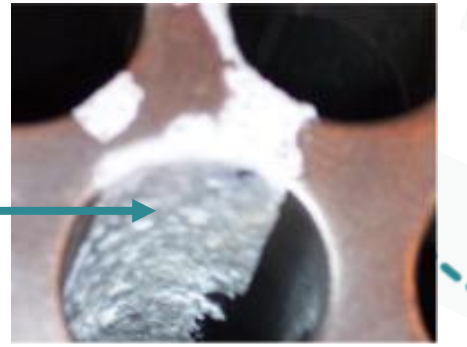
A microscopic look at the fouling mechanisms in dairy protein mixes by rheometry and microfluidics

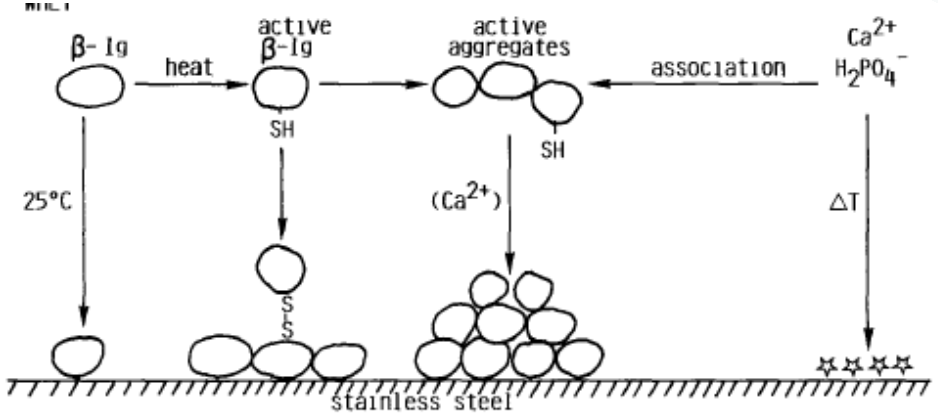
Margot GROSTETE, Romain JEANTET, Jeehyun LEE, Maude JIMENEZ, Luca LANOTTE

ICEF14 INTERNATIONAL CONGRESS ON ENGINEERING AND FOOD
June 20-23, 2023
LA CITÉ DES CONGRÈS
NANTES - FRANCE

Dairy industry : Evaporator







T.J.M Jeurnick et al., 1996

- Pressure drop
- Loss thermal efficiency

- Cleaning time, quantity of water and chemical product
- Biofilm risk

Understand the mechanism of fouling

Whey proteins

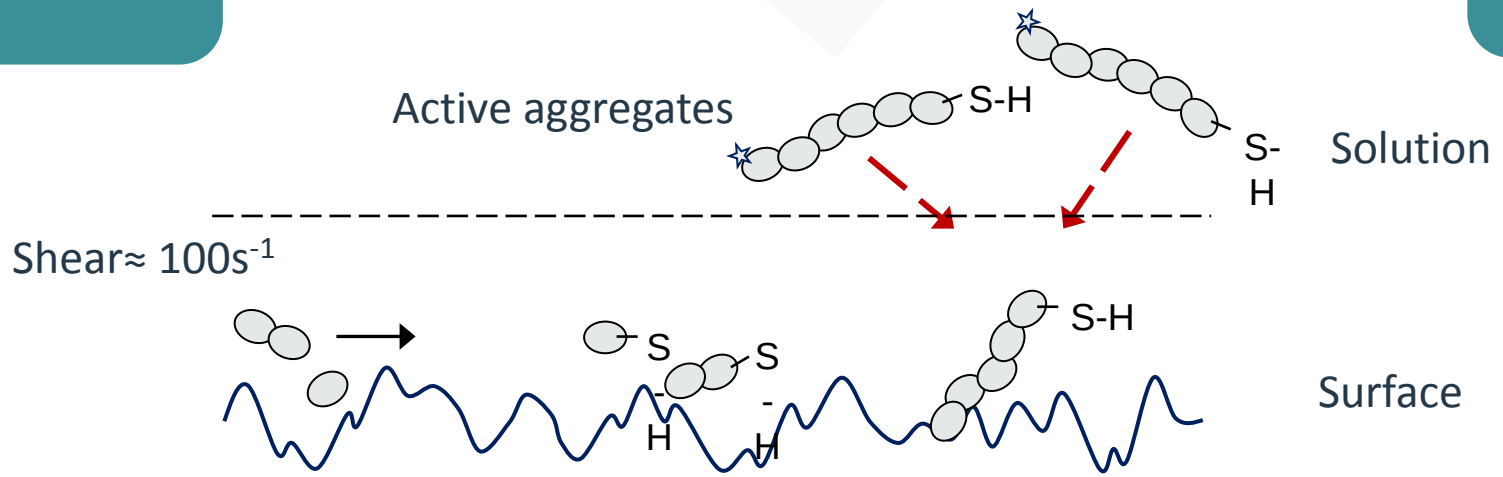
Evaporator condition

Impact of the shear on the aggregation and deposit

Fouling initiation : at the wall surface or in the solution

Rheometry and microscopy

Microfluidics



Litterature : Effect of shear on the aggregation

Reference	Type	Geometry	Shear rate / rotation speed
Taylor, freyer, 1994	Rheology	Cone/plan	0 à 40 s^{-1}
Simmons et al., 2007		Couette	111 à 625 s^{-1}
Samy Gaaloul et al., 2009		Brookfield, cylinder	28 s^{-1}
Erabit et al., 2014		Couette	0 à 400 s^{-1}
Mediwathe et al., 2018		Bob/cup	0 à 1000 s^{-1}
Quevado et al., 2020-2021		Close cavity CCR	0,06 à 50 s^{-1}
Bogathawa et al., 2020		Cylinder	1000 s^{-1}
Bogathawa et al., 2021		Bob/cup	1000 s^{-1}
Wolz et al., 2016		Mooney/Erwart	100 à 1452 s^{-1}
Moakes et al., 2015		Cylinder	200 à 800 s^{-1}
Byrne et al., 2002	Heat exchanger condition	Stirrer	100 à 1639 s^{-1}
Santos et al.,2006		Flow cell	135 ;205 et 157 ; 238 s^{-1}
Kerche et al., 2016		Tubular exchanger	/
Zhang et al., 2019		Spinning disc apparatus	/
Clarkson et al., 1999		Bubble column apparatus	/
Walkenstrom et al., 1999		Spinning disc apparatus	100,500,900 or 1300 RPM
Koh et al., 2014		Ultraturax Stainless tubular container	17,500 min^{-1} 1000 min^{-1}
Vilotte et al., 2021	Microfluidics	Continious small scale milifluidics	32 à 2666 s^{-1}

Condition of treatment :

- T°C too high (~ 80°C), predominant effect?

- No concentration gradient

- Differences in shearing

Litterature : Effect of shear on the aggregation

Even if :

Articles explain the effect of shearing :

- Increase aggregates [$C_{protein}$] < 10%
- Decrease aggregates [$C_{protein}$] > 10 %

Santos at al (2006)

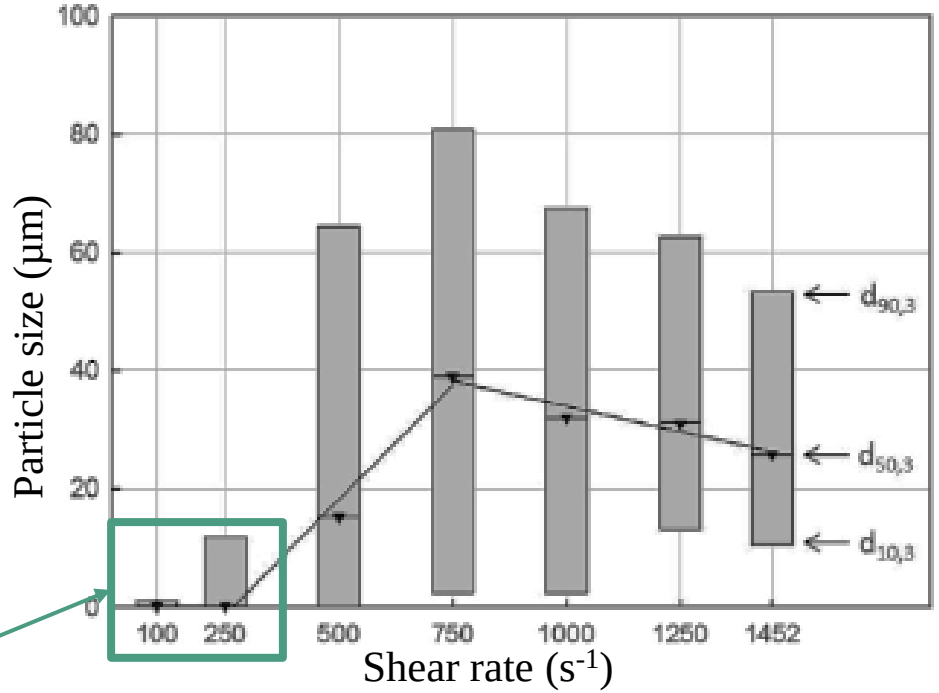
Simmons at al (2007)

Moakes at al (2015)

Erabit at al (2014)

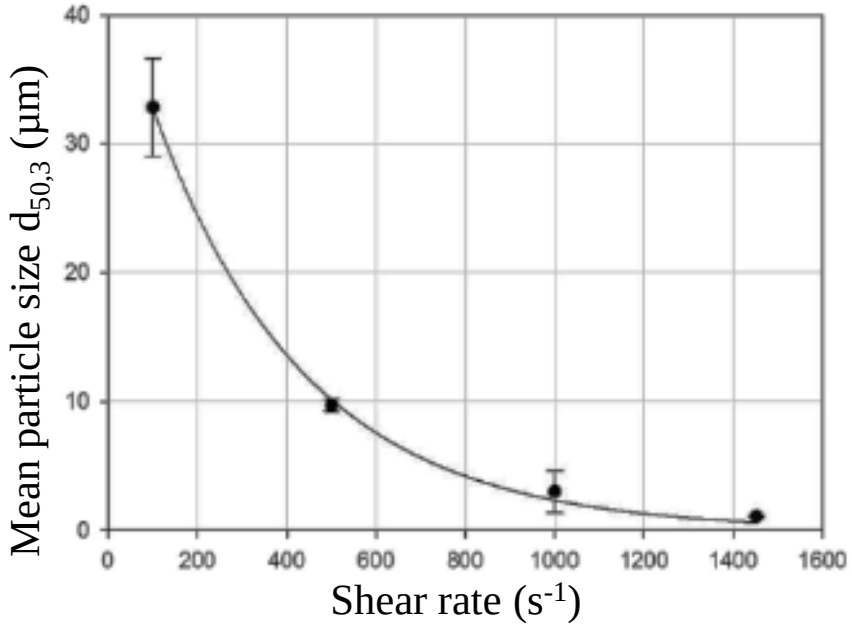
Wolz at al (2016)

Bogahawatha at al (2020)



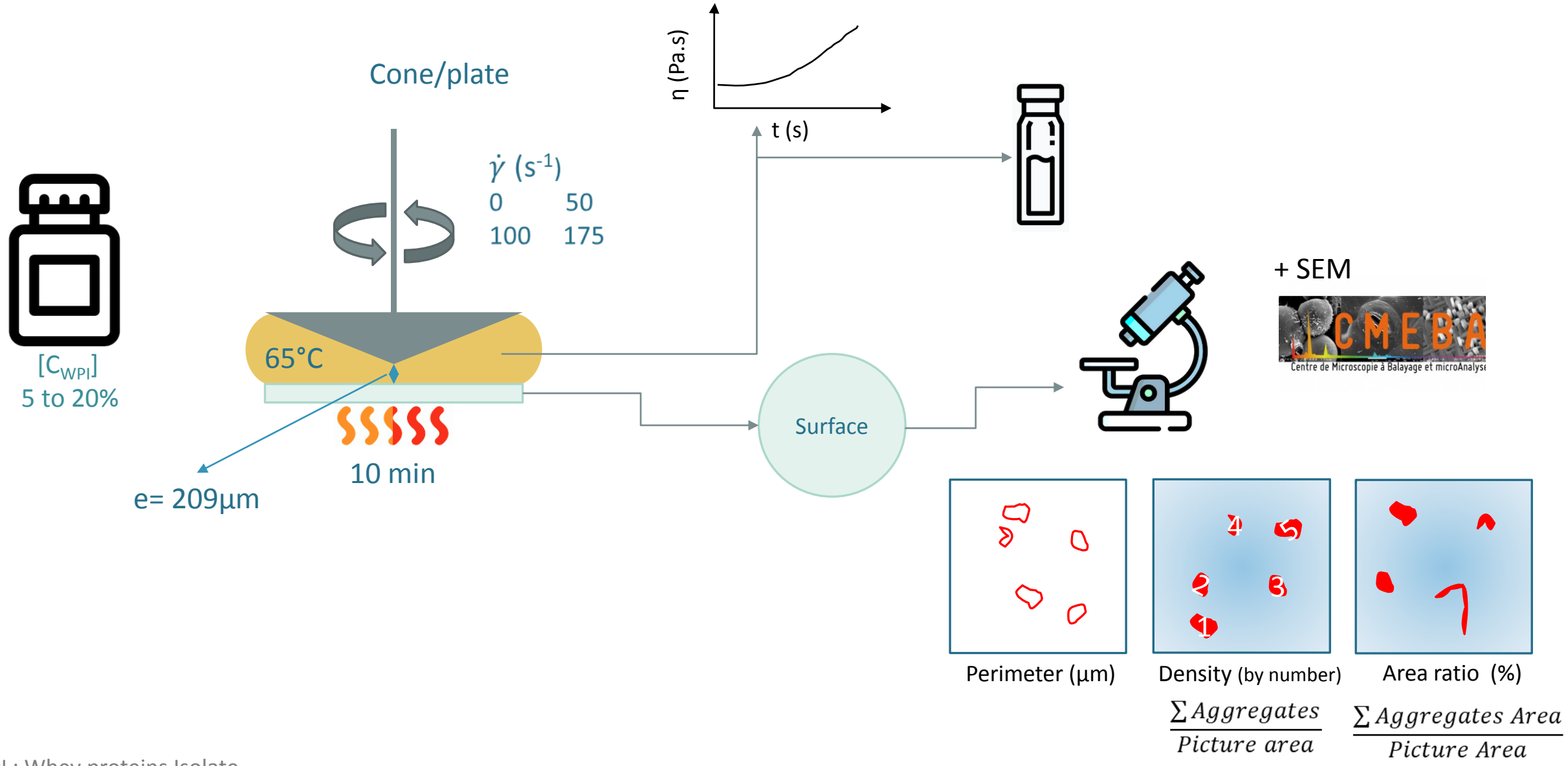
Shear working range for the evaporator

Influence of shear rate on the particle size of whey protein solutions with $C_{protein}$ = 5% heated at 80°C for 10min with a degree of denaturation > 95%



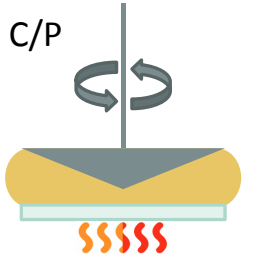
Influence of shear rate on the mean particle size $d_{50,3}$ for a protein concentration of 30% heated 80°C for 10s with a degree of denaturation of > 95%

(M. Wolz et al, 2016)



WPI : Whey proteins Isolate

C/P



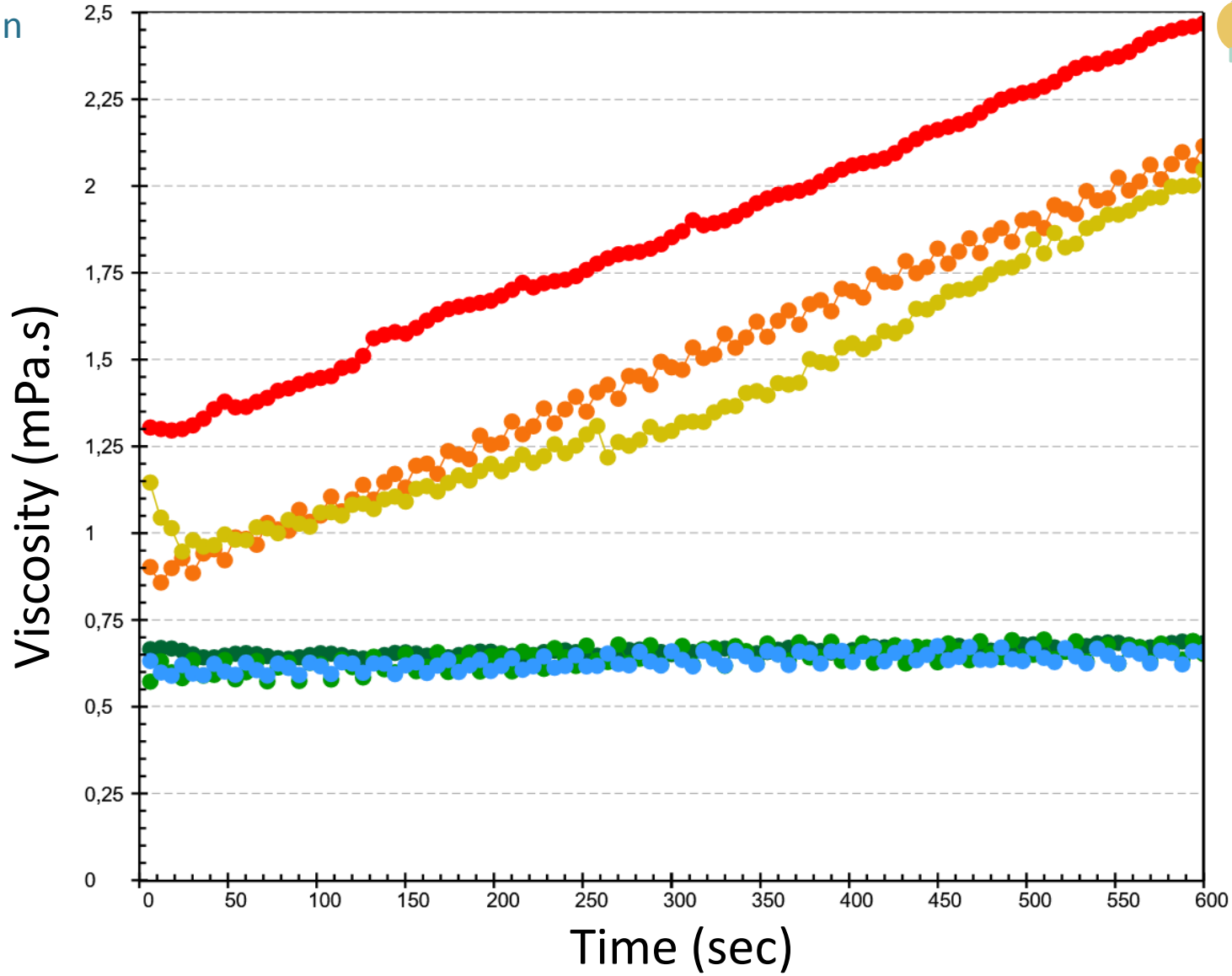
Viscosity curves of 5 and 10% WPI solution

$[C_{WPI}] = 10\%$

175 s^{-1}
100 s^{-1}
50 s^{-1}

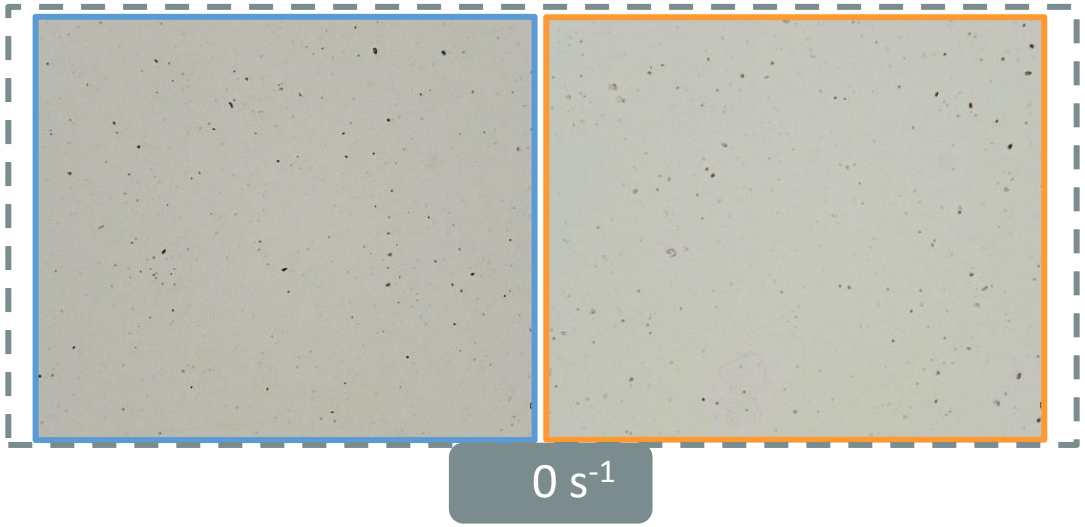
$[C_{WPI}] = 5\%$

175 s^{-1}
100 s^{-1}
50 s^{-1}

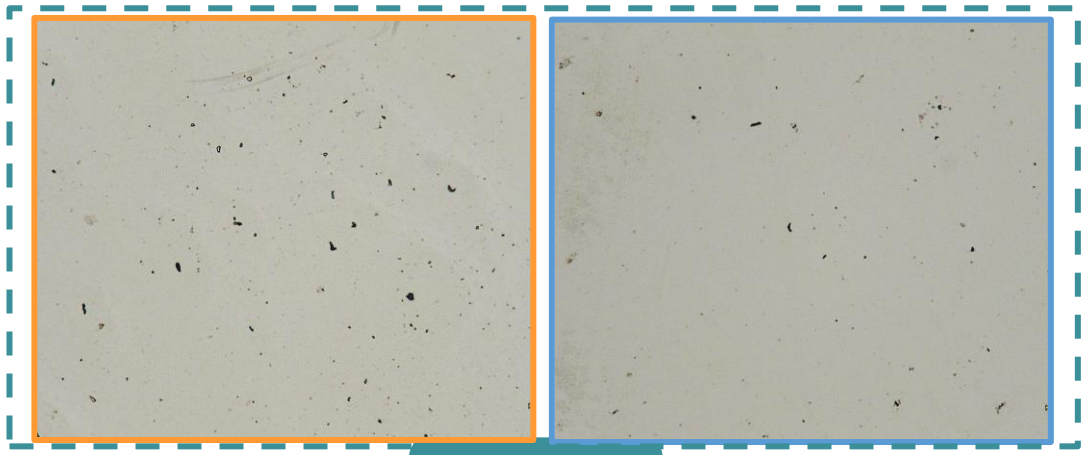


Microscopy General observation (G*500) - SURFACE

$[C_{WPI}] = 5\%$ $[C_{WPI}] = 10\%$



0 s^{-1}

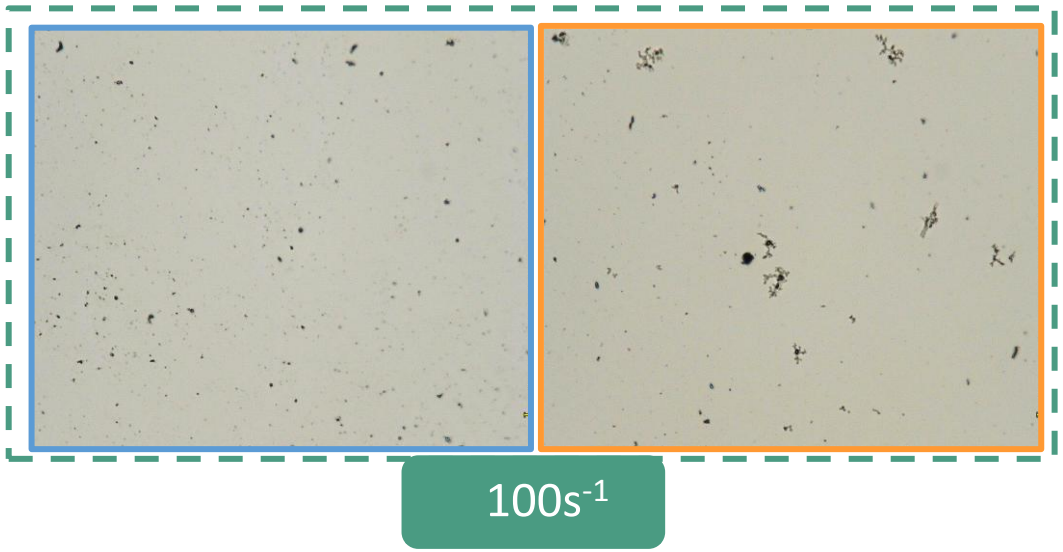


50 s^{-1}

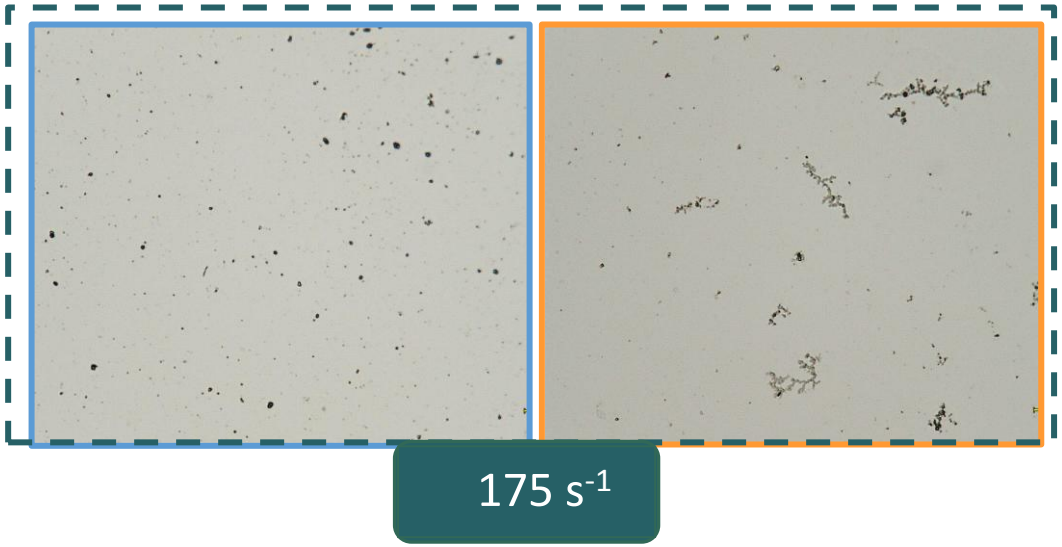
Increase Shear (s^{-1})

Increase Deposits and Size

10% : Fractal aggregates

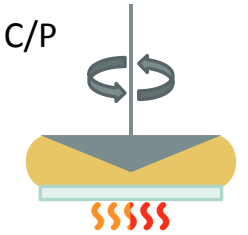


100s^{-1}



175 s^{-1}

C/P



Microscopy WPI surface : Statistical analyses - AREA RATIO

$$\frac{\sum Aggregates\ Area}{Picture\ Area}$$

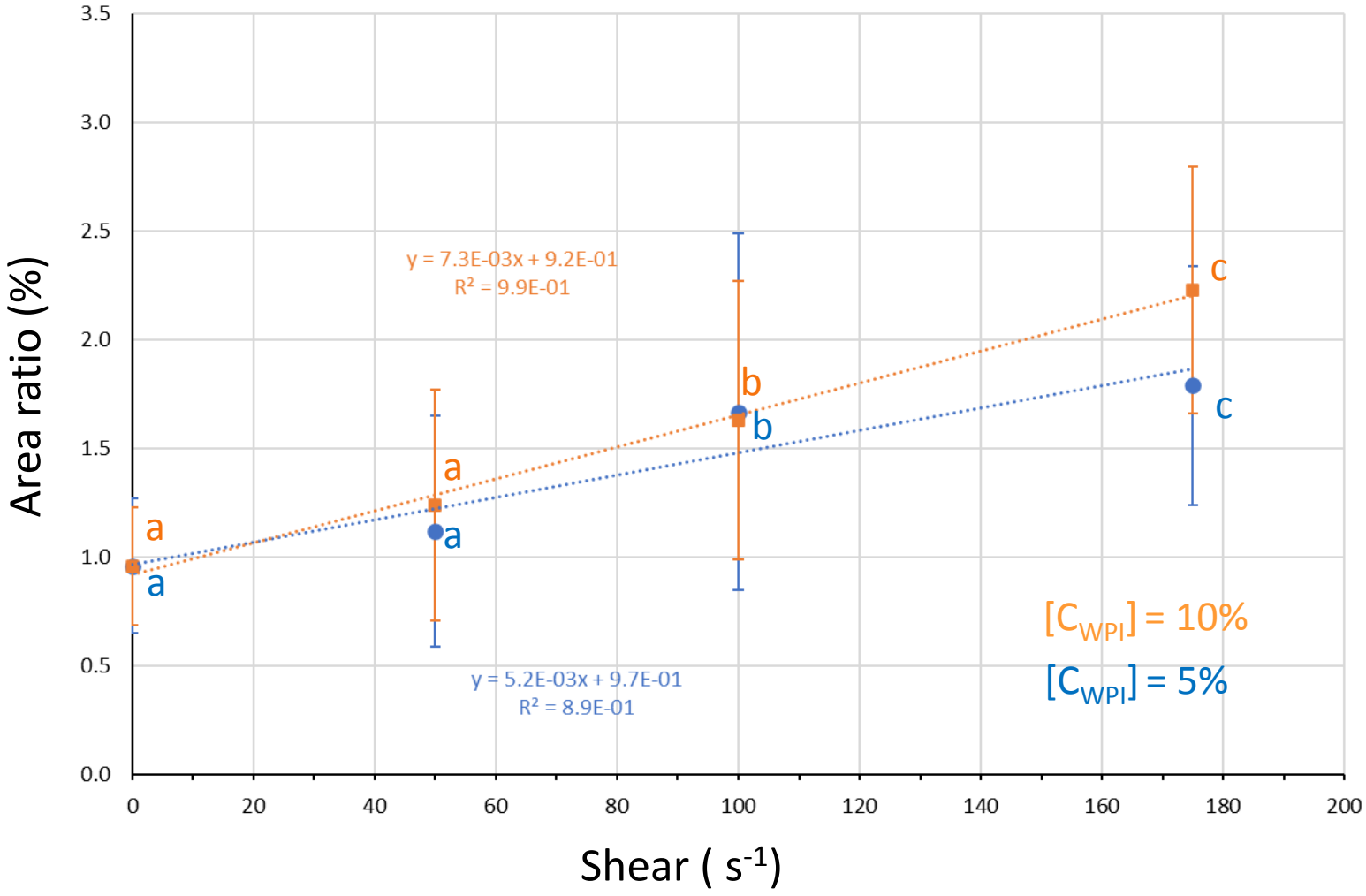
Anova :

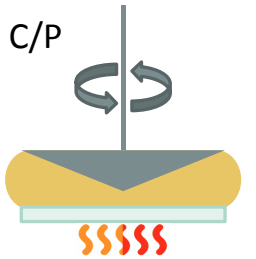
- No interaction between Concentration and shearing
- $y = \mu + \dot{\gamma}_i + C_j + \varepsilon$

Fisher :

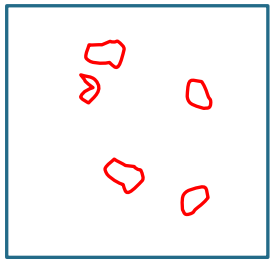
- Significant shear effect
- No concentration effect

Classification by the Post hoc test with one modality: shear





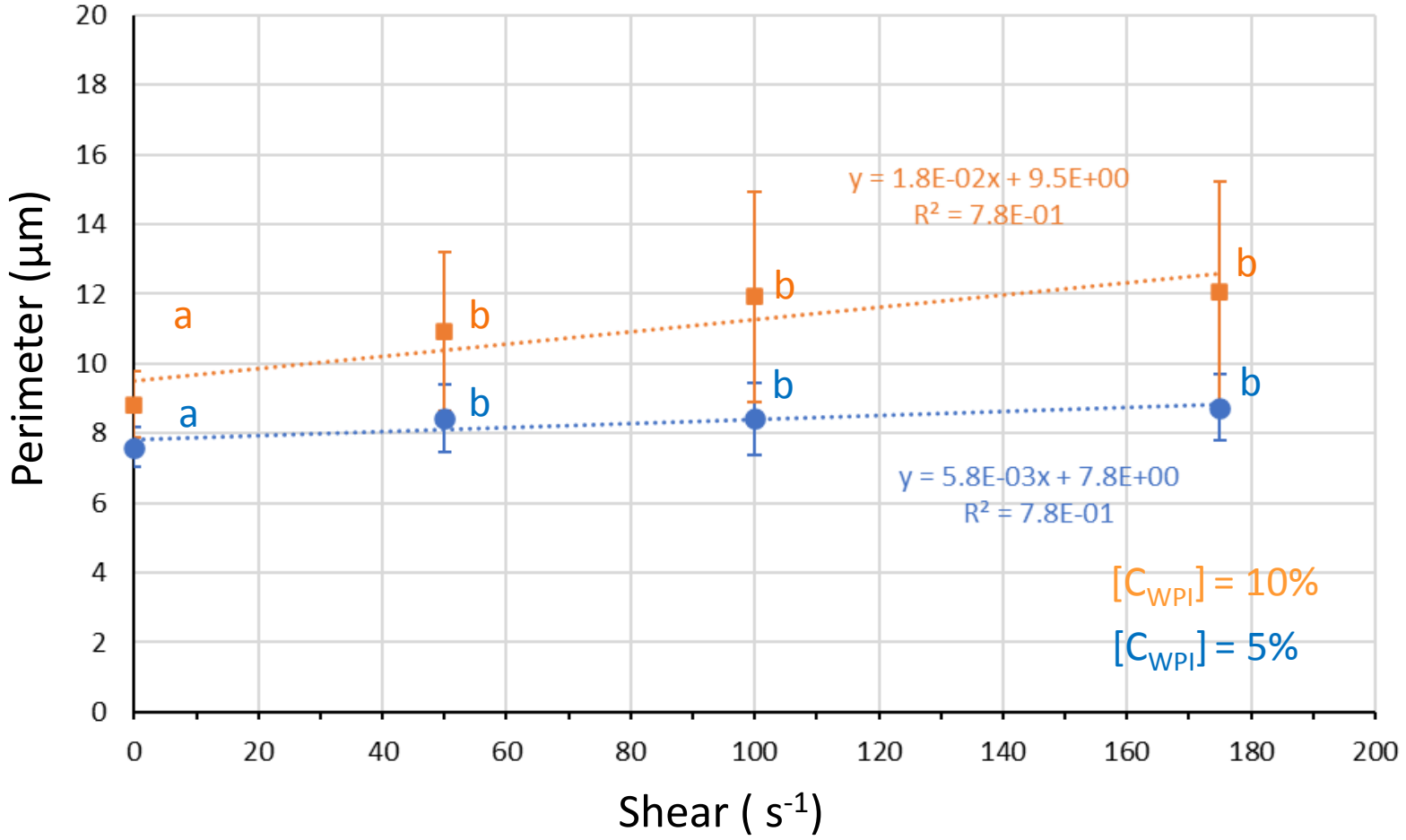
Microscopy WPI surface : Statistical analyses - PERIMETER



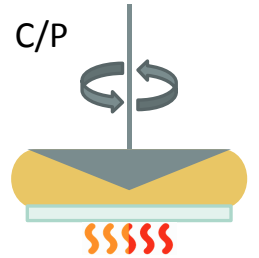
Anova :

- Interaction between shear and concentration
- $y = \mu + \dot{\gamma}_i + C_j + (\dot{\gamma}_i * C_j) + \varepsilon$

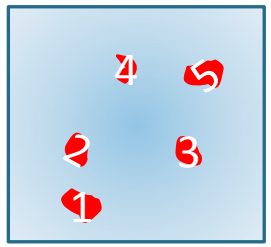
Classification by the Post hoc test with one modality: shear



C/P



Microscopy WPI surface : Statistical analyses - DENSITY



$$\frac{\sum Aggregates}{Picture\ area}$$

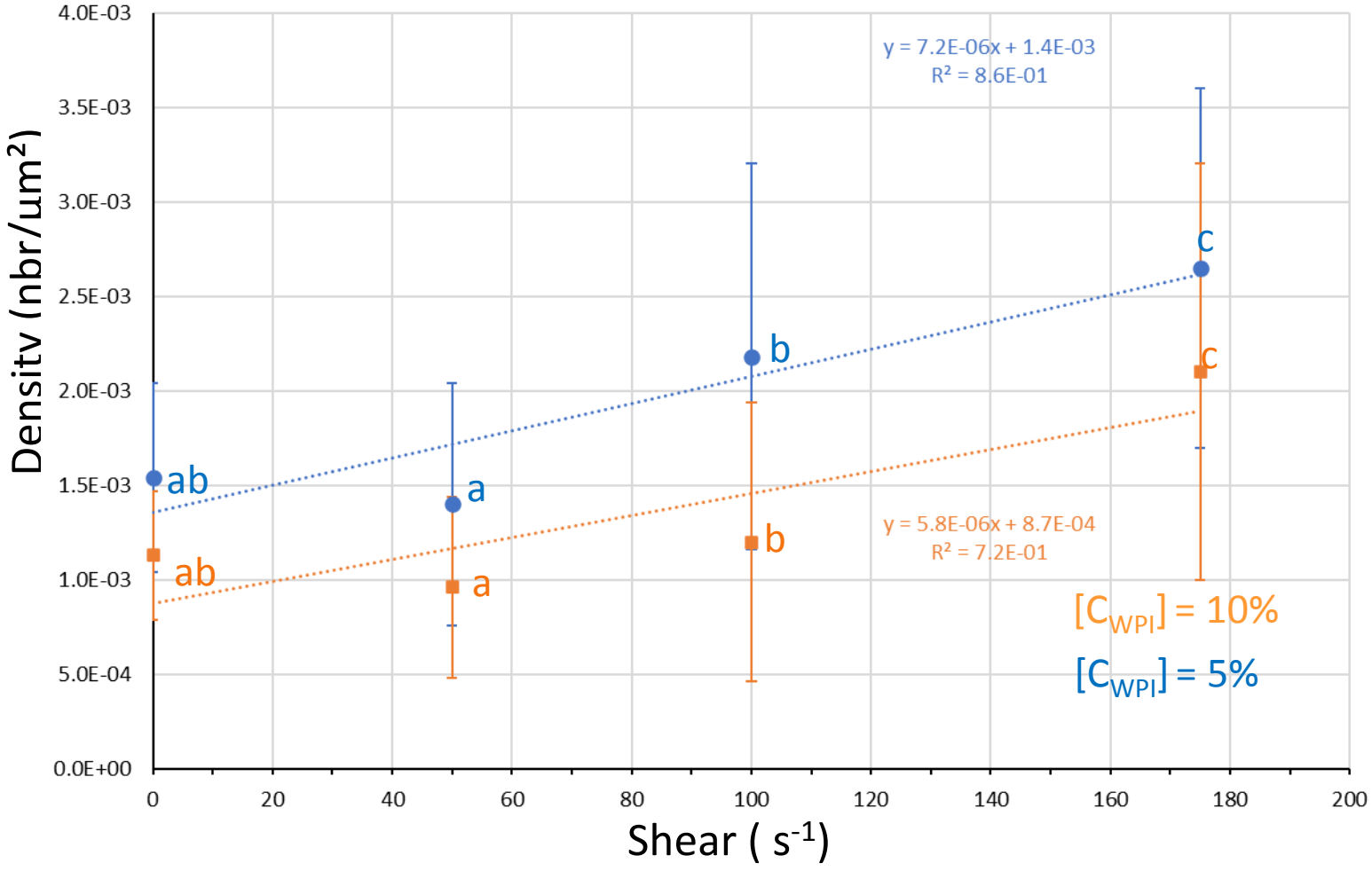
Anova :

- No interaction between shear and concentration
- $y = \mu + \dot{\gamma}_i + C_j + \varepsilon$

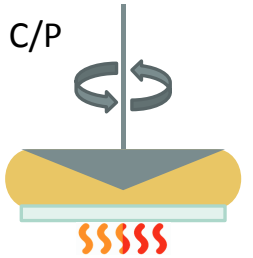
Fisher :

- Significant shear effect
- Significant concentration effect

Classification by the Post hoc test with one modality: shear



C/P



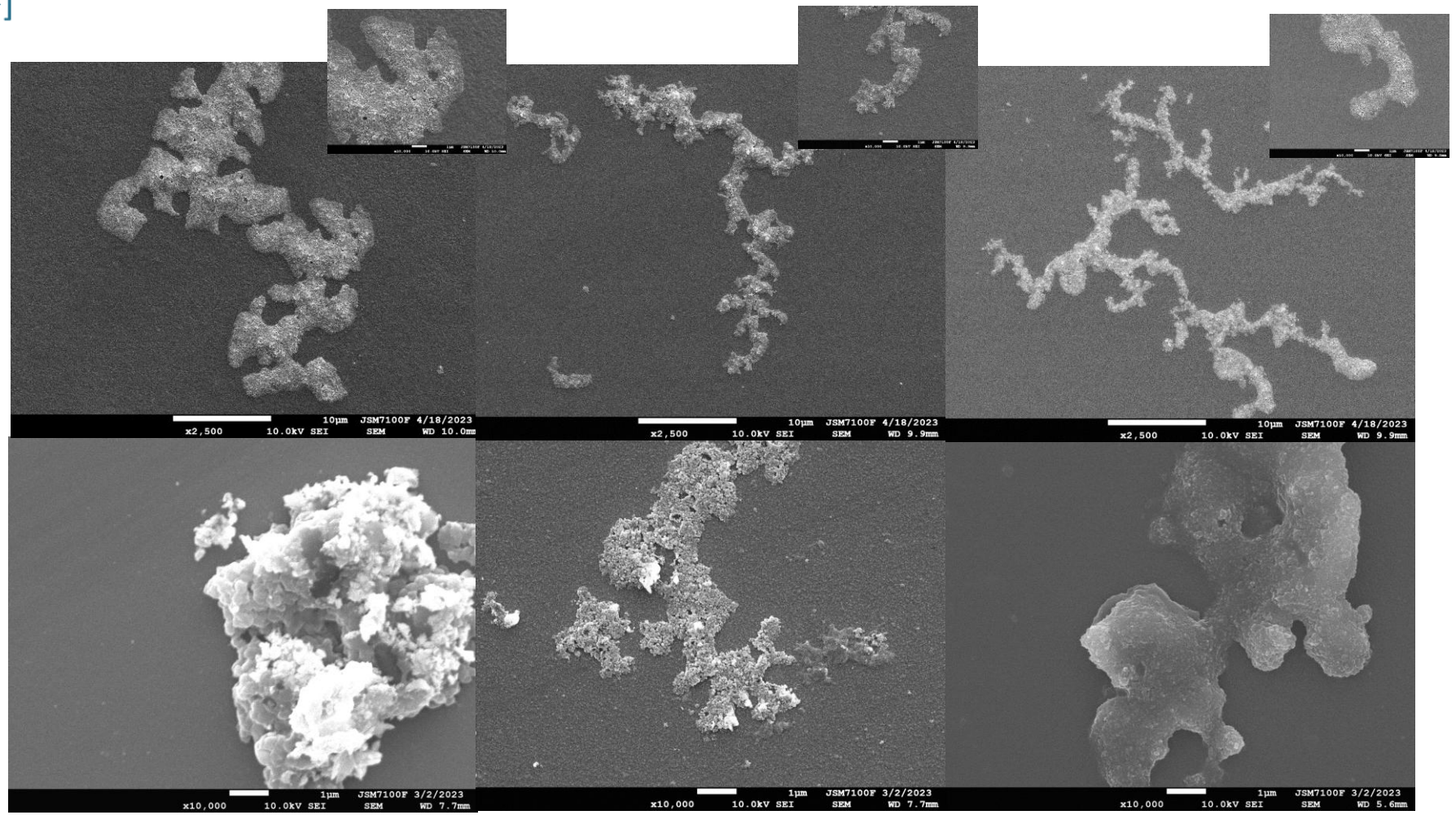
SEM 5% and 10% WPI

$[C_{WPI}]$

$[C_{WPI}]$ = 10%

Increase aggregates size

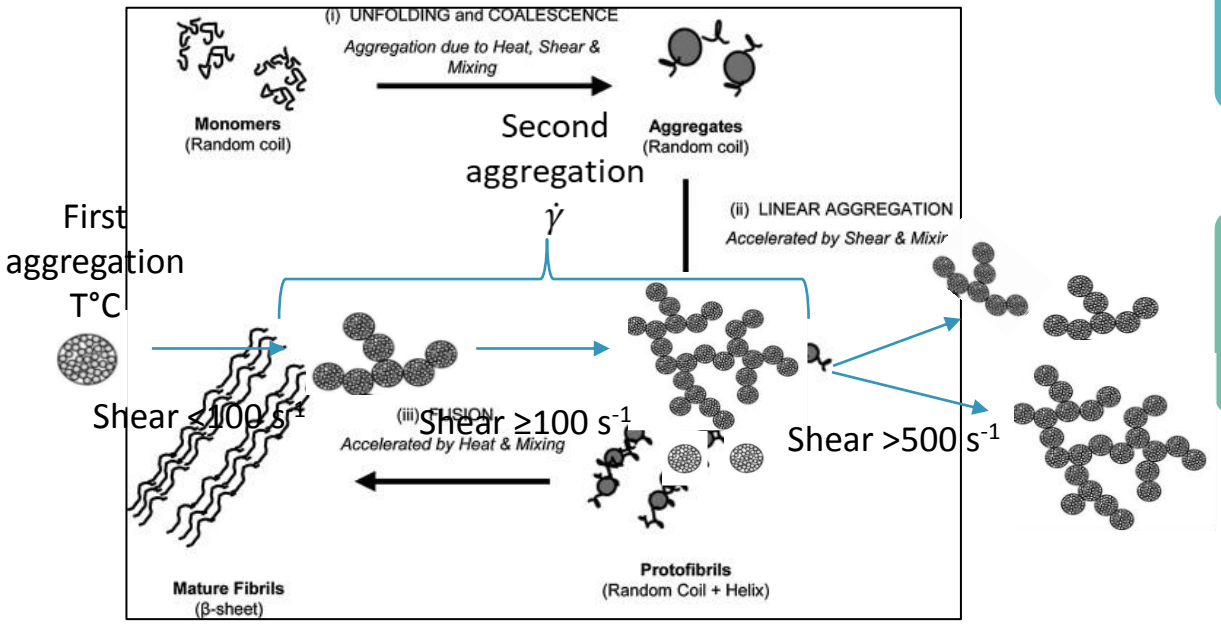
$[C_{WPI}]$ = 5%



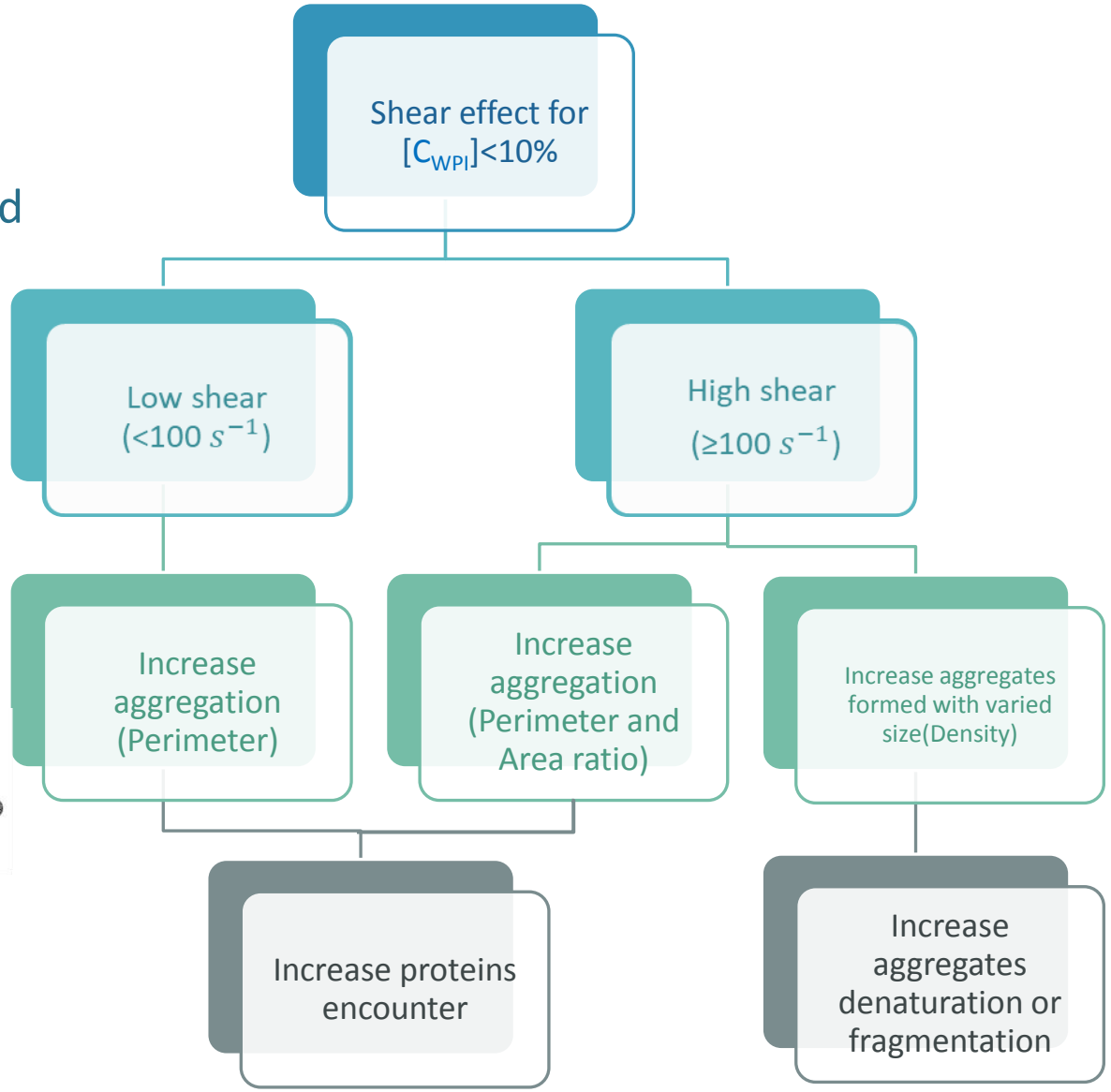
$\dot{\gamma}$

↗ $\dot{\gamma}$ → ↗ aggregates size and compactness

- Shearing have an effect on the aggregation : Quantity , compactness, size
- Concentration have an effect on the agregation : Size and structure (fractal aggregates)



I.B Bekard and D.E. Dunstand, 2014



Understand the mechanism of fouling

Whey proteins

Evaporator condition

Impact of the shear on the agregation and deposit

Fouling initiation : at the wall surface or in the solution

Rheometry and microscopy

Microfluidics

Higher concentration [$C_{protein}$] > 10% → Gel rheology study
Solution study → HPLC
Denaturation study → Fluorescence microscopy

Understand the fouling initiation and development in a continuous system

Concentration/Time/Temperature/Surface Materials
Shear ≈ 100 s^{-1}

Thank you for your attention

Merci de votre attention

Acknowledgements : Françoise BOISSEL, Florence ROUSSEAU, Pascaline HAMON, Marie Helene FAMELART, Ghazi BEN MESSAOUD

Margot GROSTETE
margot.grostete@agrocampus-ouest.fr

STLO, 2 rue de Saint Brieuc, 35000 Rennes
UMET, Cité scientifique, 59650 Villeneuve-d'Ascq