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## 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

### ► To cite this version:

Margot Grostete, Romain Jeantet, Jeehyun Lee, Maude Jimenez, Luca Lanotte, et al.. A microscopic look at the fouling mechanisms in dairy protein mixes by rheometry and microfluidics. The 14th International Congress on Engineering and Food (ICEF 2023), <https://www.icef14.com/en/committees/6>, Jun 2023, Nantes, France. hal-04142580

**HAL Id: hal-04142580**

**<https://hal.inrae.fr/hal-04142580>**

Submitted on 27 Jun 2023

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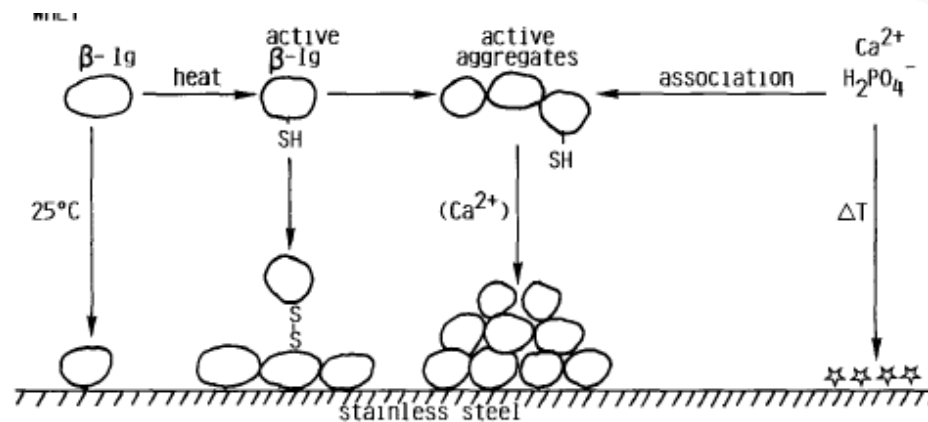
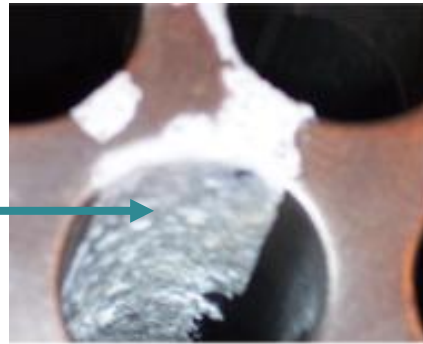
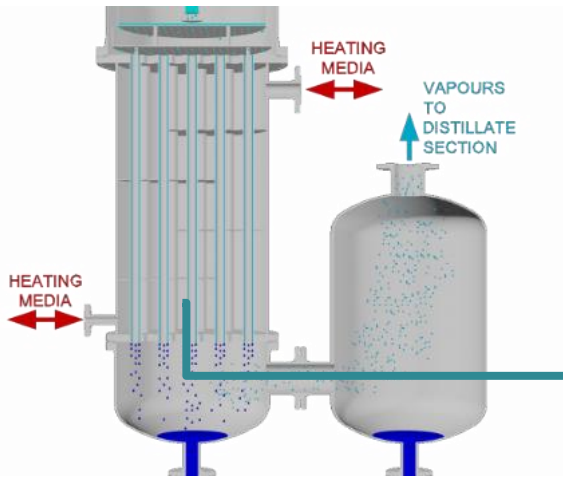
# A microscopic look at the fouling mechanisms in dairy protein mixes by rheometry and microfluidics

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

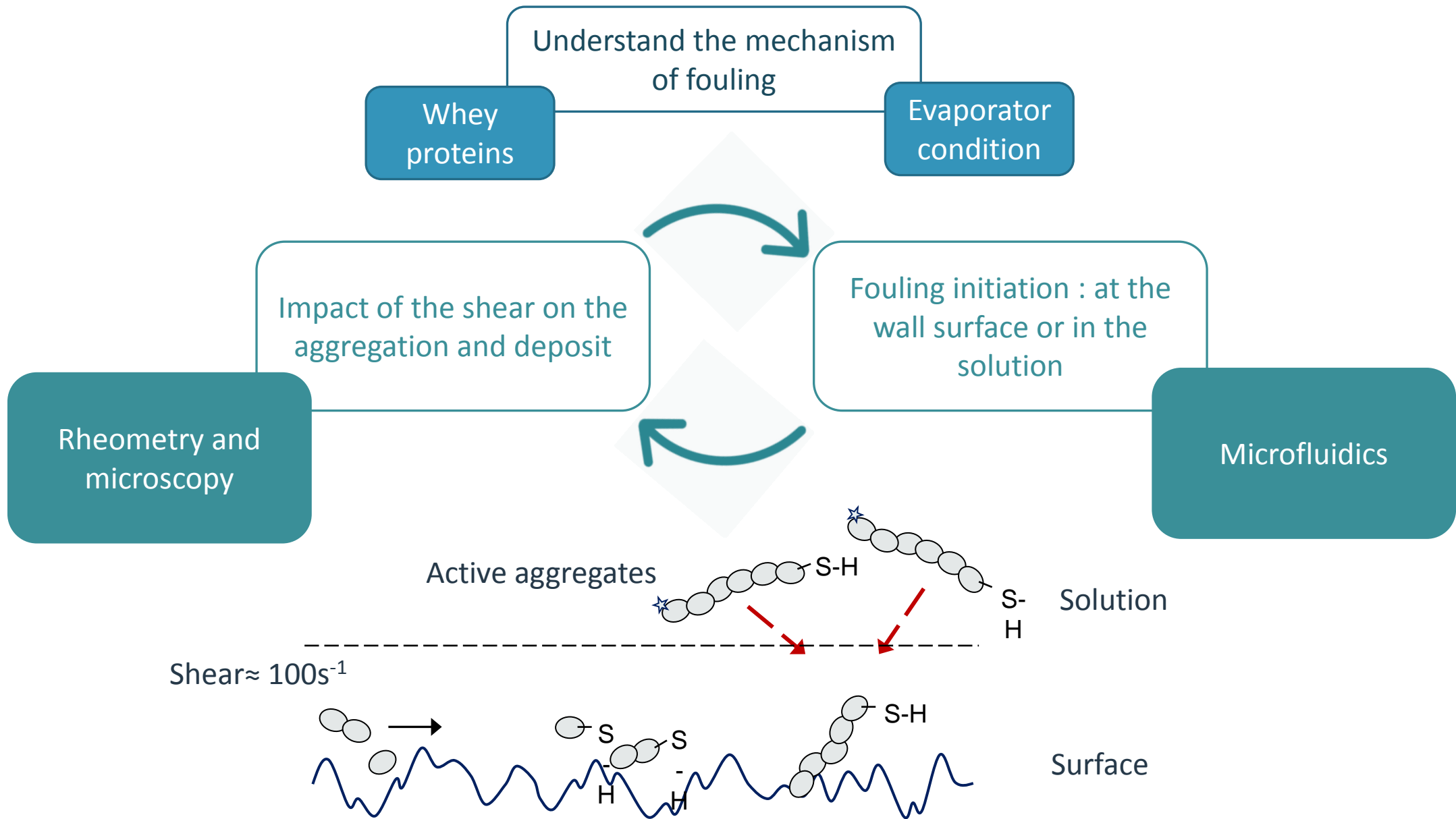


## Dairy industry : Evaporator



T.J.M Jeurnick et al., 1996

- Pressure drop
- Loss thermal efficiency
- Cleaning time, quantity of water and chemical product
- Biofilm risk



## Litterature : Effect of shear on the aggregation

Reference	Type	Geometry	Shear rate / rotation speed
Taylor, freyer, 1994	Rheology	Cone/plan	0 à 40 s <sup>-1</sup>
Simmons et al., 2007		Couette	111 à 625 s <sup>-1</sup>
Samy Gaaloul et al., 2009		Brookfield, cylinder	28 s <sup>-1</sup>
Erabit et al., 2014		Couette	0 à 400 s <sup>-1</sup>
Mediwathe et al., 2018		Bob/cup	0 à 1000 s <sup>-1</sup>
Quevado et al., 2020-2021		Close cavity CCR	0,06 à 50 s <sup>-1</sup>
Bogathawa et al., 2020		Cylinder	1000 s <sup>-1</sup>
Bogathawa et al., 2021		Bob/cup	1000 s <sup>-1</sup>
Wolz et al., 2016		Mooney/Erwart	100 à 1452 s <sup>-1</sup>
Moakes et al., 2015		Cylinder	200 à 800 s <sup>-1</sup>
Byrne et al., 2002	Heat exchanger condition	Stirrer	100 à 1639 s <sup>-1</sup>
Santos et al., 2006		Flow cell	135 ; 205 et 157 ; 238 s <sup>-1</sup>
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 <sup>-1</sup> 1000 min <sup>-1</sup>
Vilotte et al., 2021	Microfluidics	Continious small scale milifluidics	32 à 2666 s <sup>-1</sup>

### 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 [ $C_{\text{protein}}$ ] < 10%
- Decrease aggregates [ $C_{\text{protein}}$ ] > 10 %

*Santos et al (2006)*

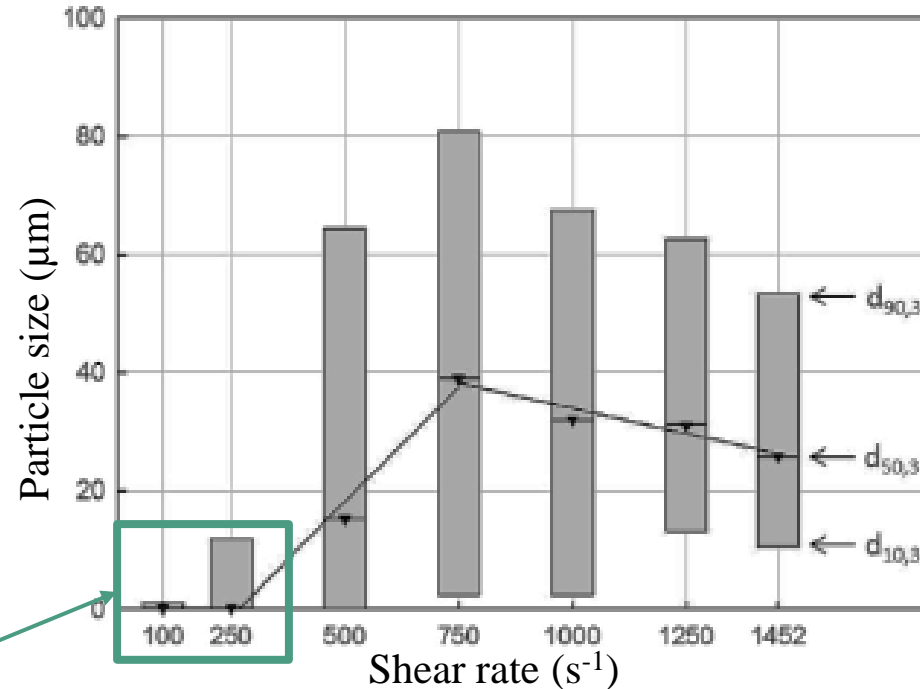
*Simmons et al (2007)*

*Moakes et al (2015)*

*Erabit et al (2014)*

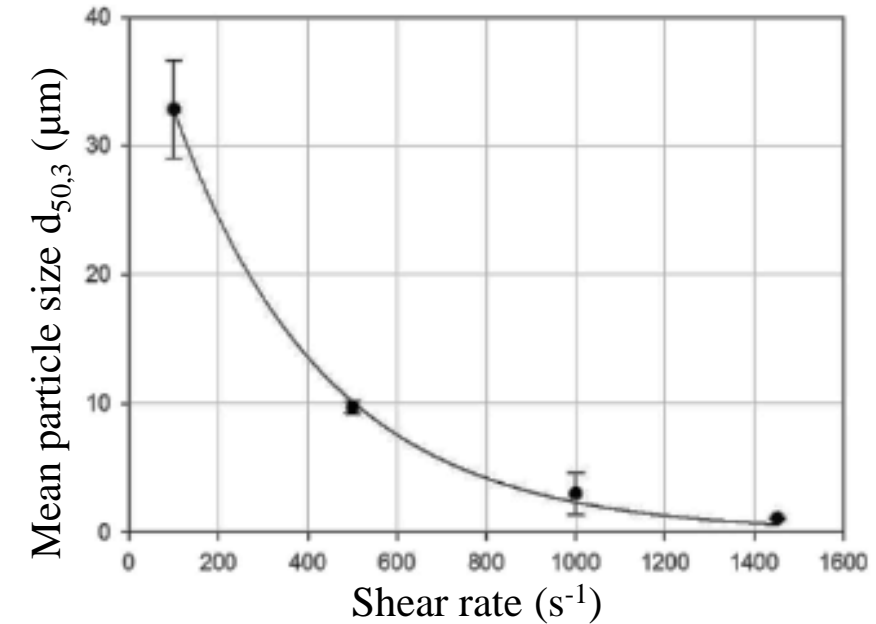
*Wolz et al (2016)*

*Bogahawatha et al (2020)*



Shear working range  
for the evaporator

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



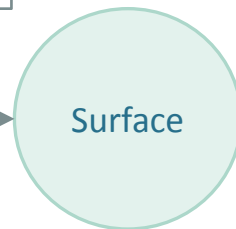
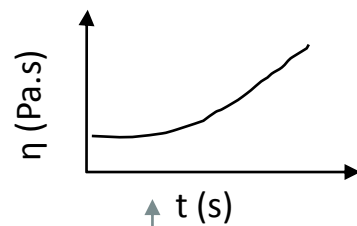
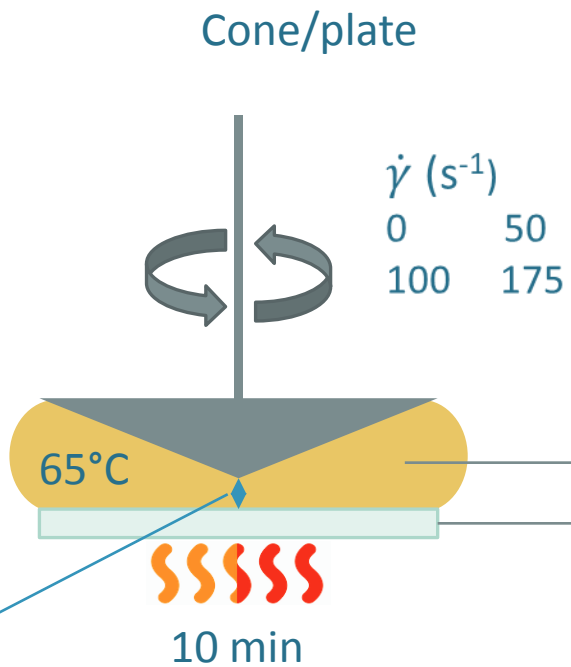
Influence of shear rate on the mean particle size  $d_{50,3}$  for a protein  
concentration of 30% heated  $80^{\circ}\text{C}$  for 10s with a degree of  
denaturation of > 95%

(*M. Wolz et al, 2016*)

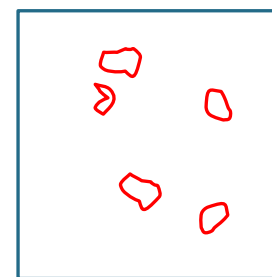


$[C_{WPI}]$   
5 to 20%

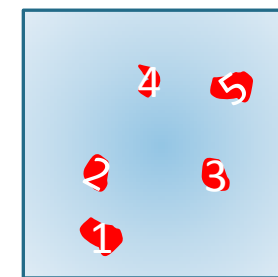
$e = 209 \mu\text{m}$



+ SEM

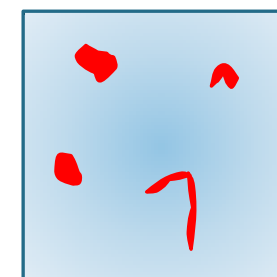


Perimeter ( $\mu\text{m}$ )



Density (by number)

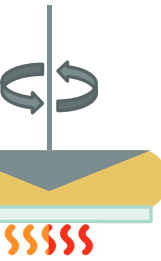
$$\frac{\sum \text{Aggregates}}{\text{Picture area}}$$



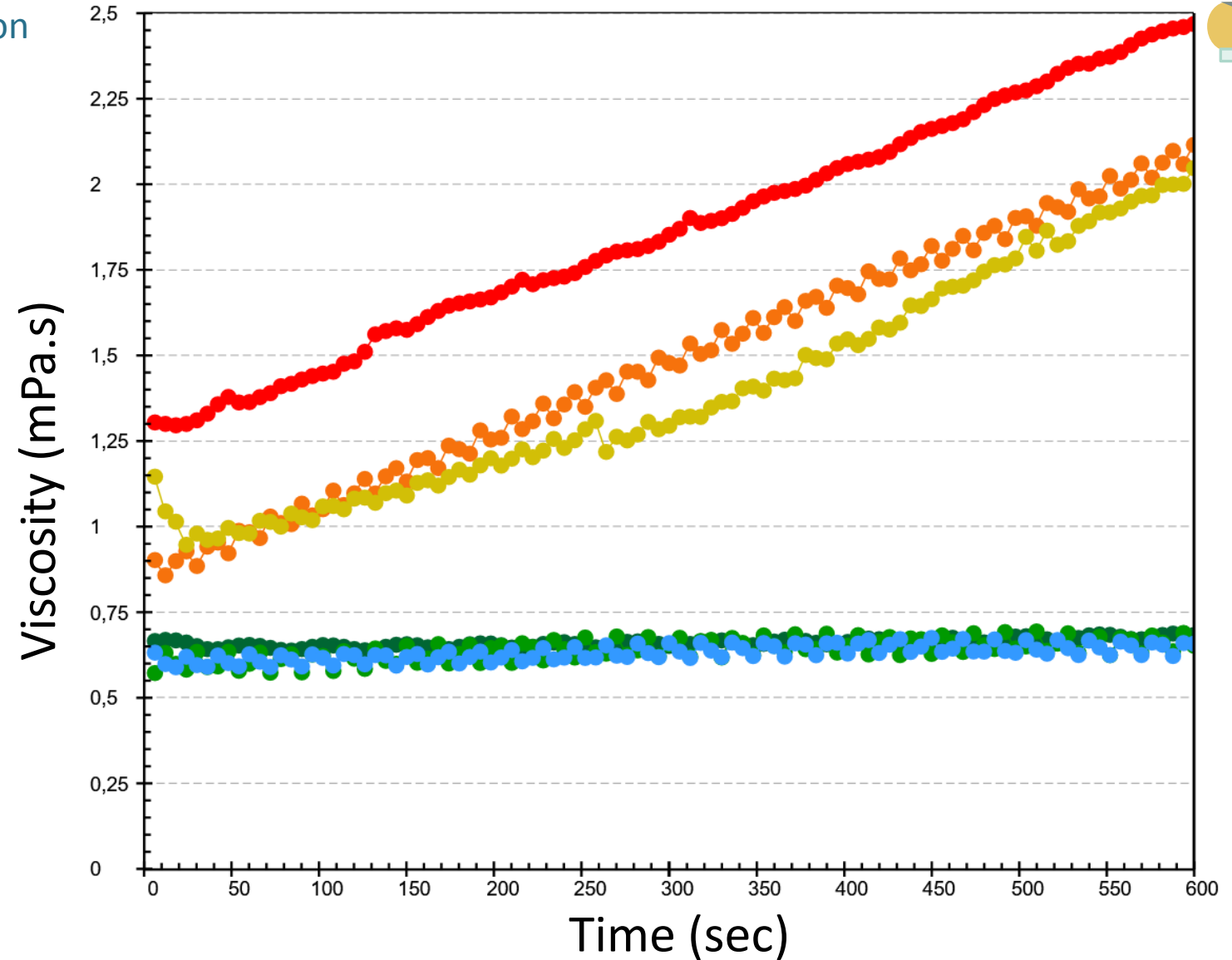
Area ratio (%)

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

WPI : Whey proteins Isolate

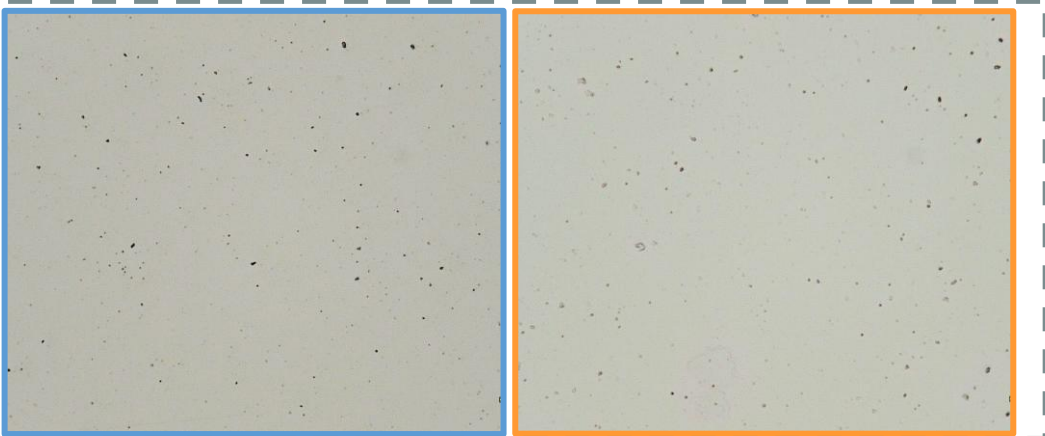
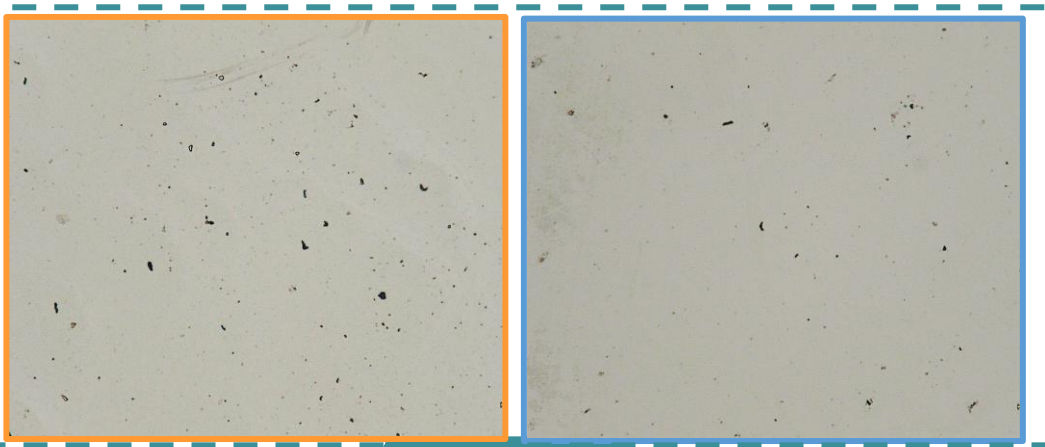
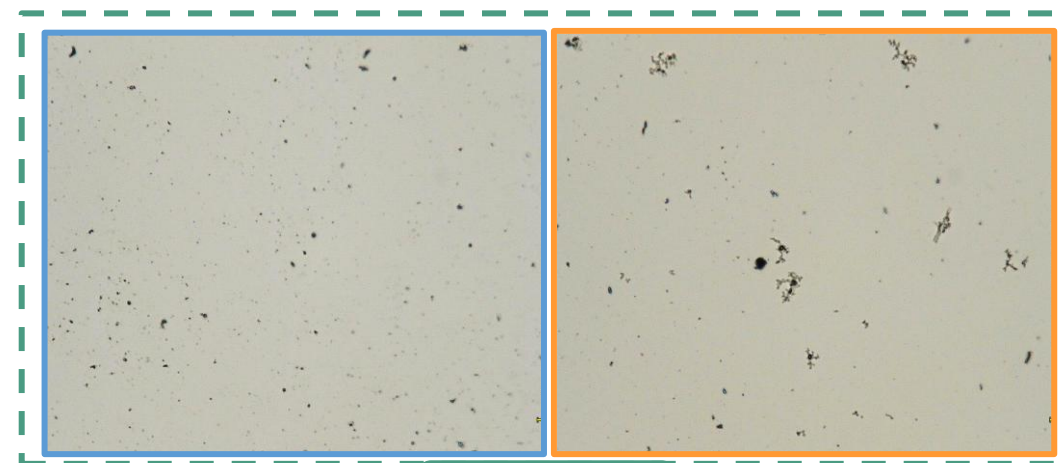
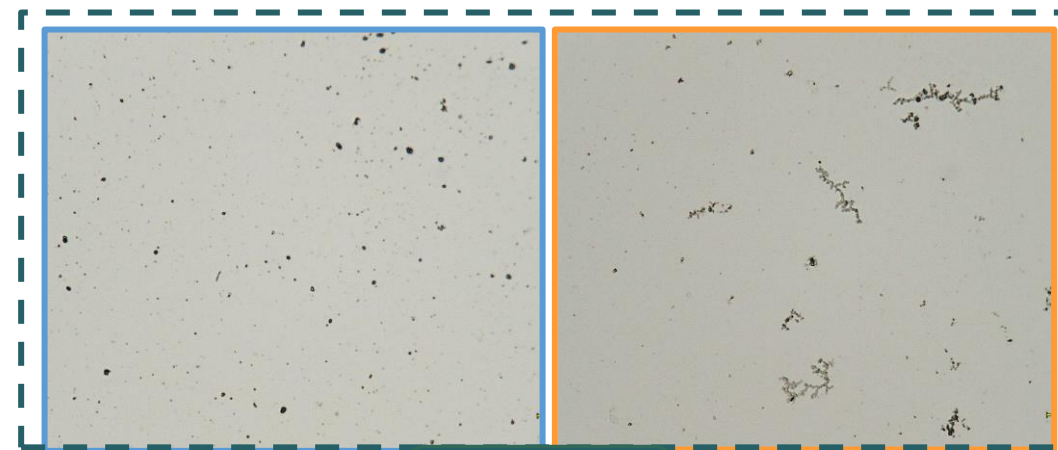


## Viscosity curves of 5 and 10% WPI solution

 $[C_{\text{WPI}}] = 10\%$  $175 \text{ s}^{-1}$   
 $100 \text{ s}^{-1}$   
 $50 \text{ s}^{-1}$  $[C_{\text{WPI}}] = 5\%$  $175 \text{ s}^{-1}$   
 $100 \text{ s}^{-1}$   
 $50 \text{ s}^{-1}$ 

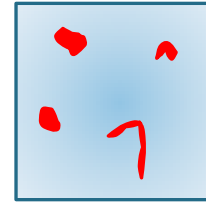


## Microscopy General observation (G\*500) - SURFACE

 $[C_{WPI}] = 5\%$   $[C_{WPI}] = 10\%$ 0 s<sup>-1</sup>50 s<sup>-1</sup>Increase  
Shear (s<sup>-1</sup>)Increase  
Deposits and  
Size  
10% : Fractal  
aggregates100 s<sup>-1</sup>175 s<sup>-1</sup>



## Microscopy WPI surface : Statistical analyses - AREA RATIO



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

Anova :

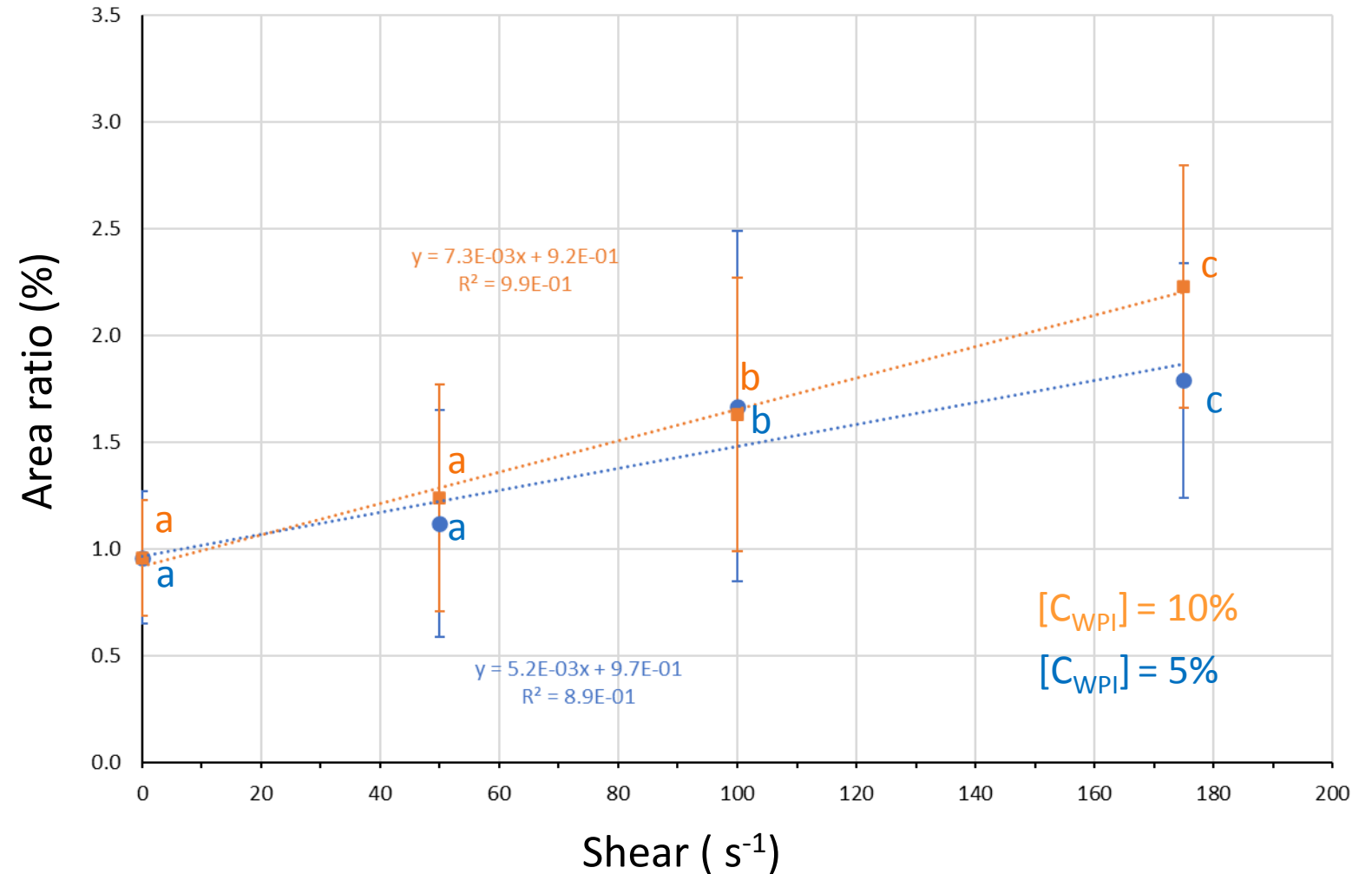
- No interaction between Concentration and shearing

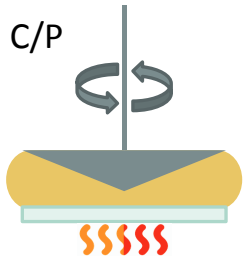
$$y = \mu + \gamma_i + C_j + \varepsilon$$

Fisher :

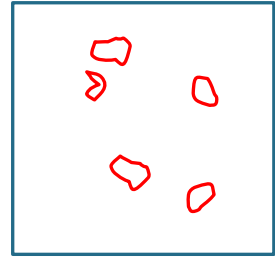
- Significant shear effect
- No concentration effect

Classification by the Post hoc test with one modality: **shear**





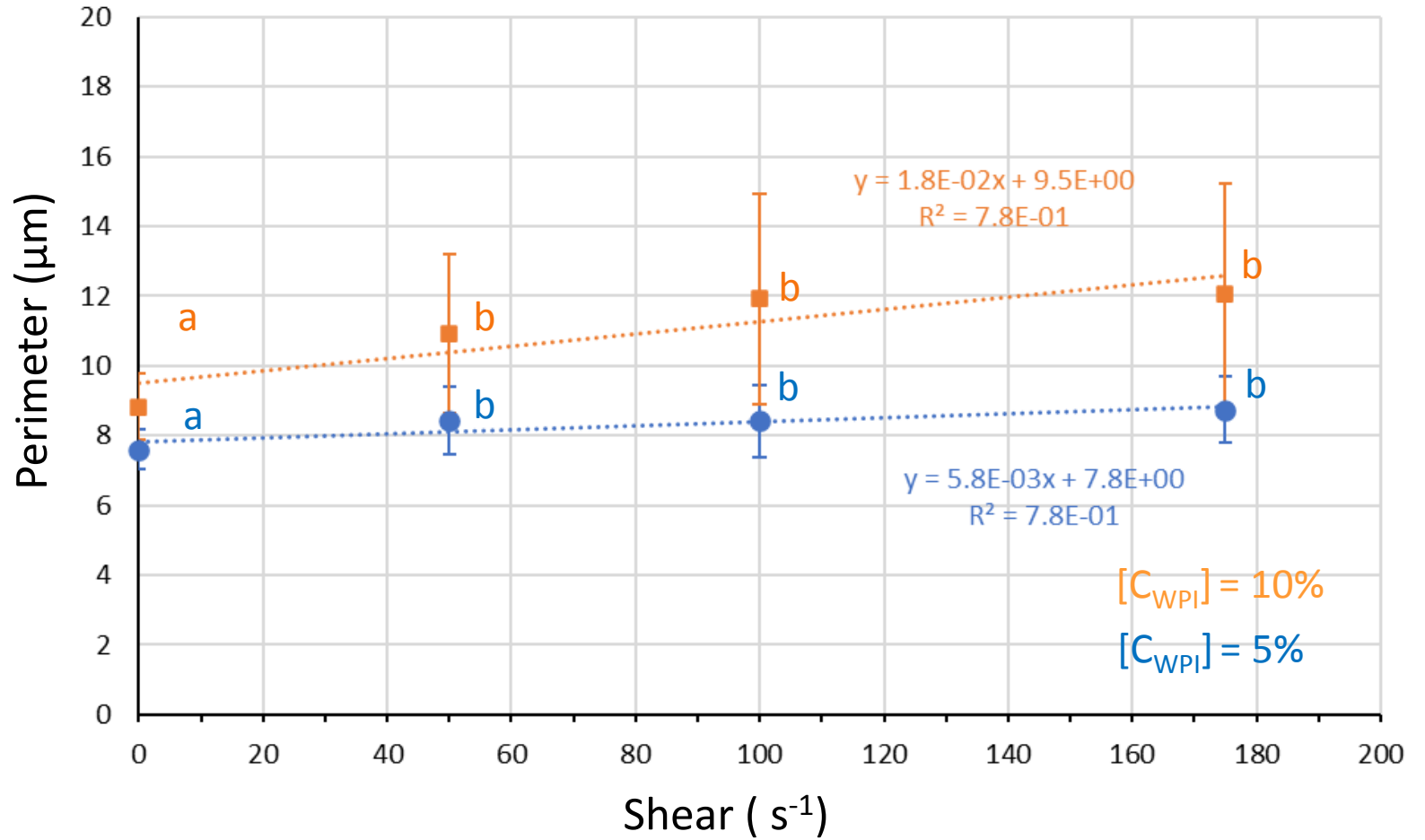
## Microscopy WPI surface : Statistical analyses - PERIMETER

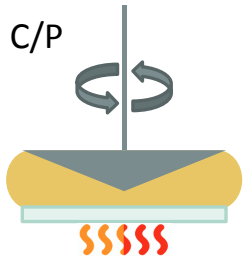


Anova :

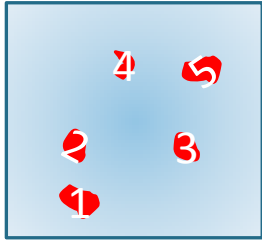
- Interaction between shear and concentration
- $y = \mu + \dot{\gamma}_i + C_j + (\dot{\gamma}_i * C_j) + \epsilon$

Classification by the Post hoc test with one modality: shear





## Microscopy WPI surface : Statistical analyses - DENSITY



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

Anova :

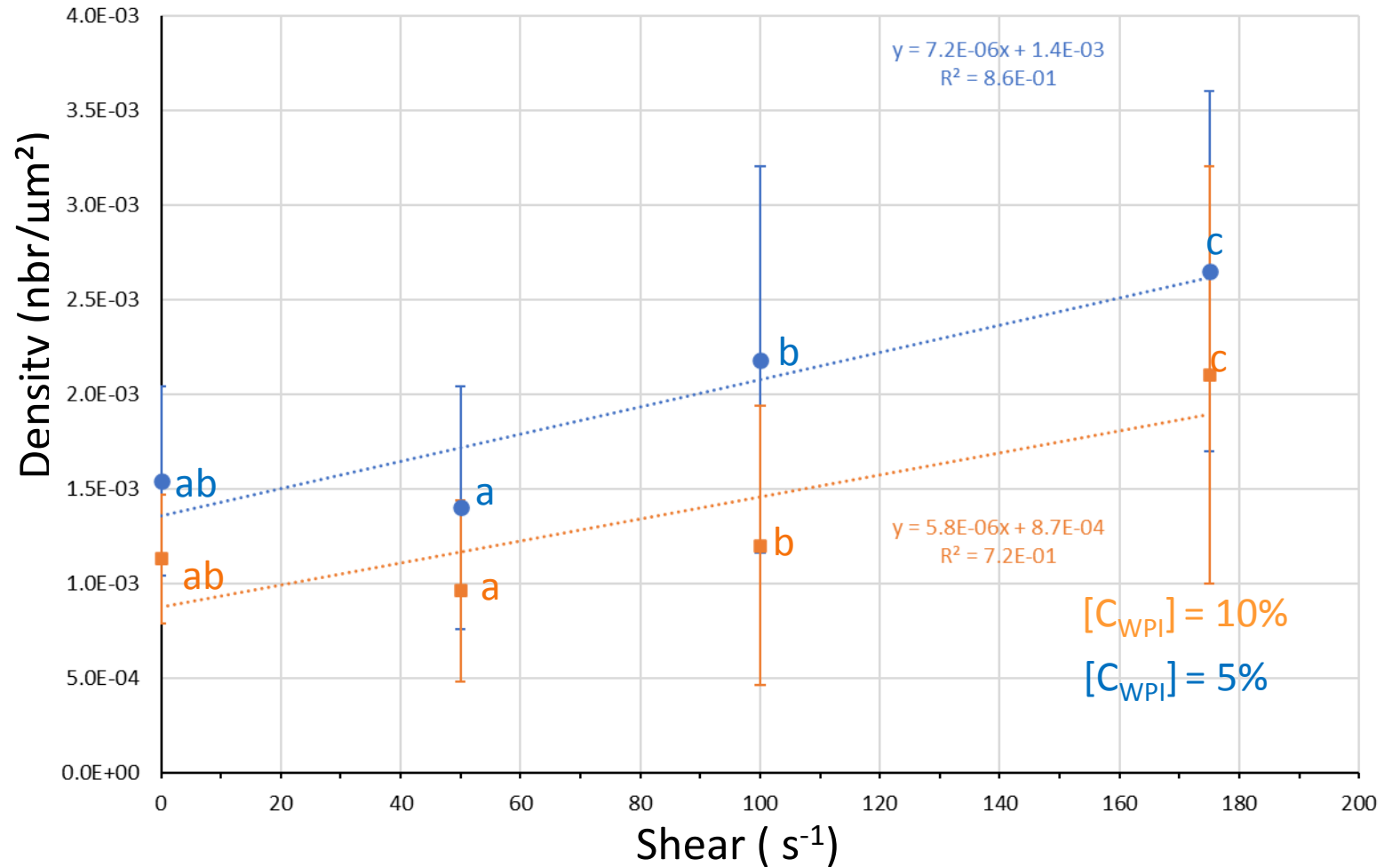
- No interaction between shear and concentration

$$y = \mu + \gamma_i + C_j + \varepsilon$$

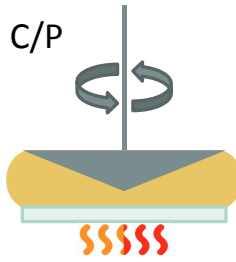
Fisher :

- Significant shear effect
- Significant concentration effect

Classification by the Post hoc test with one modality: **shear**



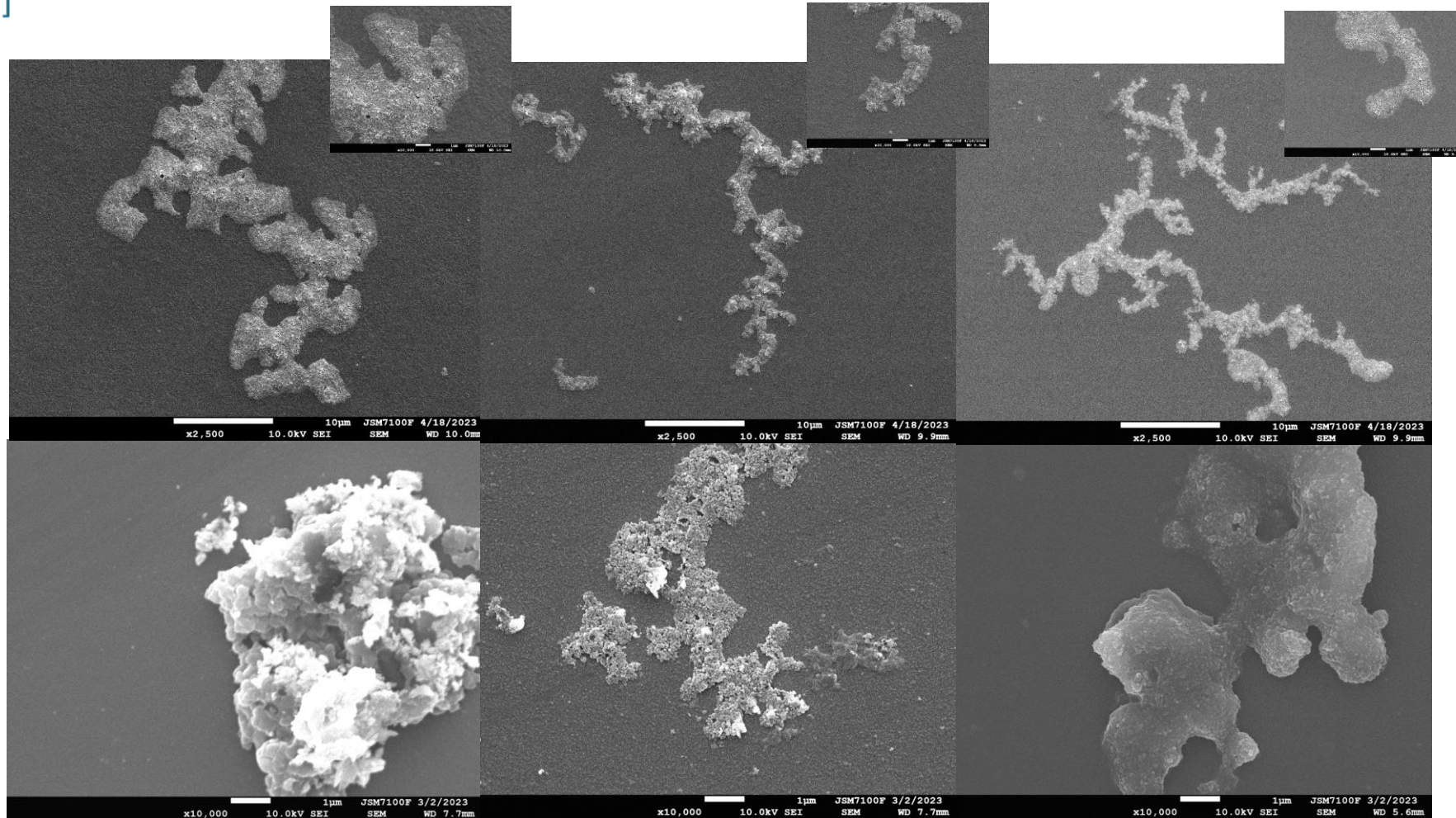




## SEM 5% and 10% WPI

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

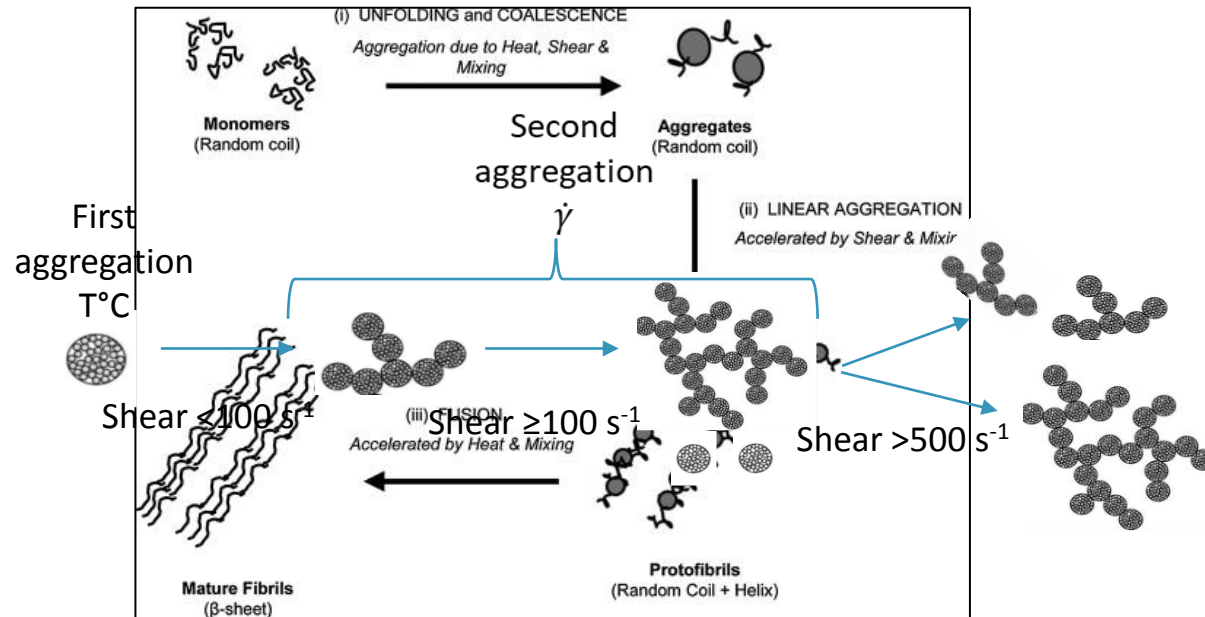

Increase  
aggregates  
size


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


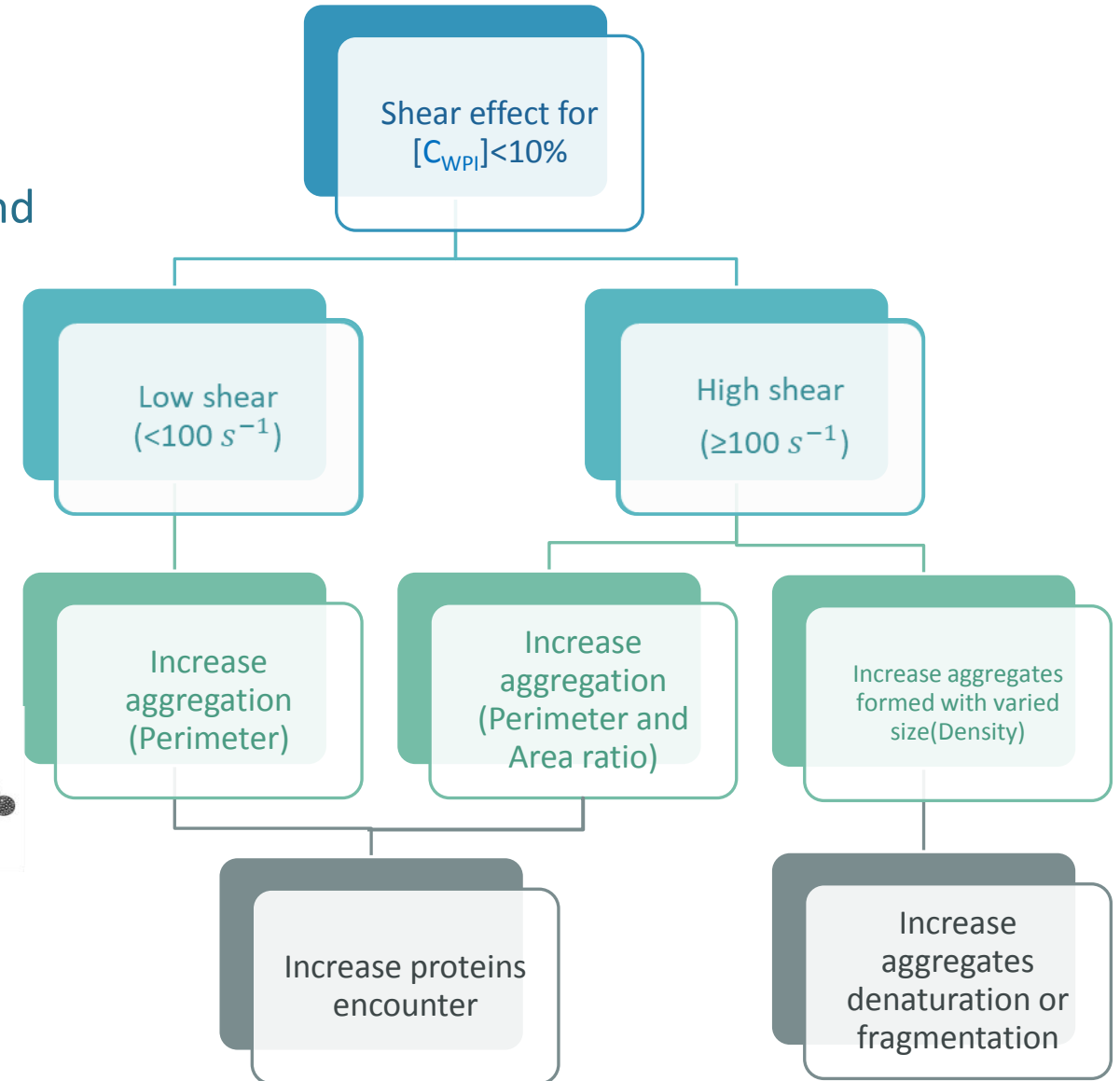
$\uparrow \dot{\gamma} \rightarrow \rightarrow$  aggregates size and compactness

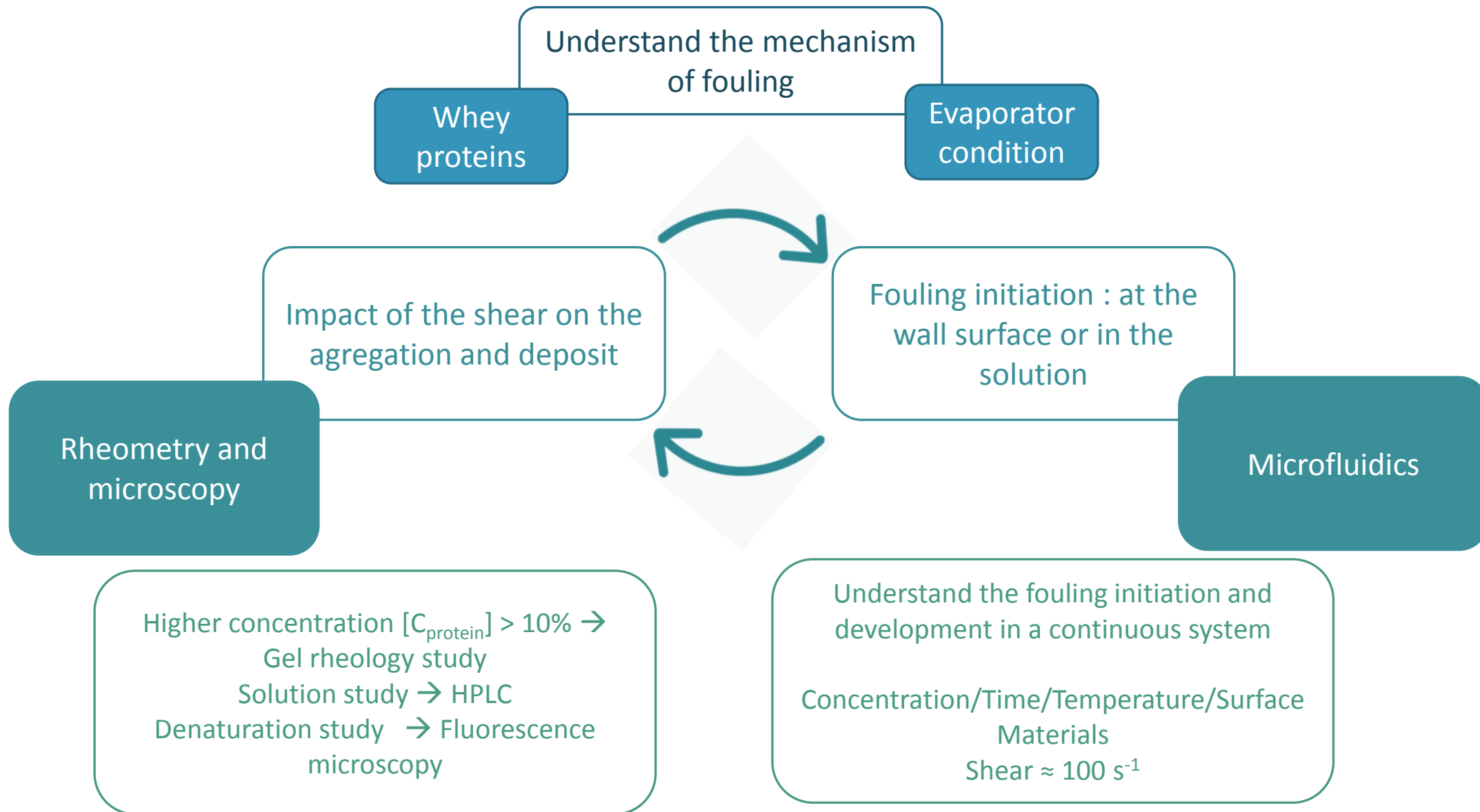
 $\dot{\gamma}$

- 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





Thank you for your attention

Merci de votre attention

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

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