



New insights on fouling mechanisms explored by rheo-fluidics at the microscale

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➤ New insights on fouling mechanisms explored by rheo-fluidics at the microscale

M. Grostete, J. Lee, Z. Msibi, F. Boissel, M. Jimenez, R. Jeantet, L. Lanotte

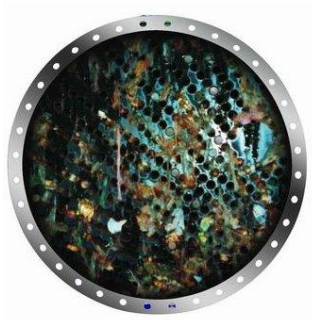


XVIII Italian Society of Rheology Conference
Capri Island (Naples, Italy), 12th-14th September 2024

> The fouling process in dairy industry

What is fouling?

Accumulation of solid components
of the dairy solutions
on stainless-steel surface



Where do we observe fouling?

Membranes, filters
(filtration process)

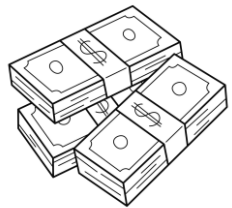
Evaporators, heat exchangers
(pasteurization, sterilization)

DIFFERENT SCALE
AND PHYSICO-CHEMICAL DYNAMICS

Which are the consequences?

- Significant pressure drop
- Lowered thermal exchange
- Pipe blockage

Daily cleaning sessions



Visser J and Jeurnink Th J M (1997). Experimental Thermal and Fluid Science.

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> The emerging question of the evaporators



Concentration of dairy fluids before spray drying (energy saving)



Spraying Systems Co.®

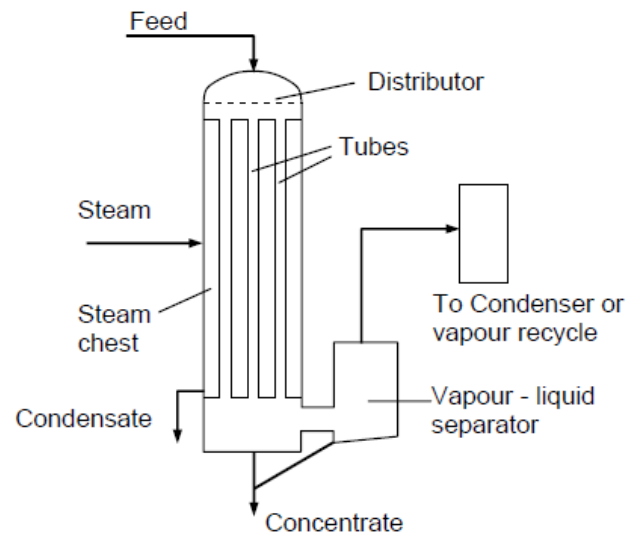
Production of "commodities"

Wide range of processed fluids

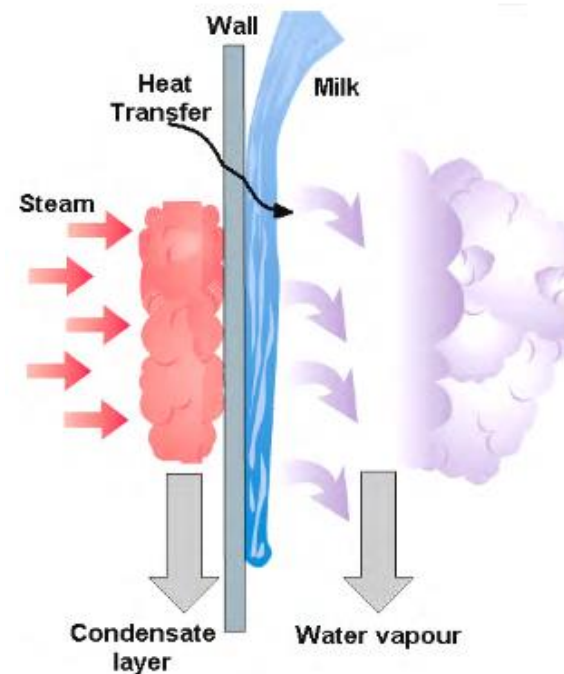
Infant Milk Formulas (IMFs)



FALLING FILM SETUP



Broome S., 2005.



Main characteristics

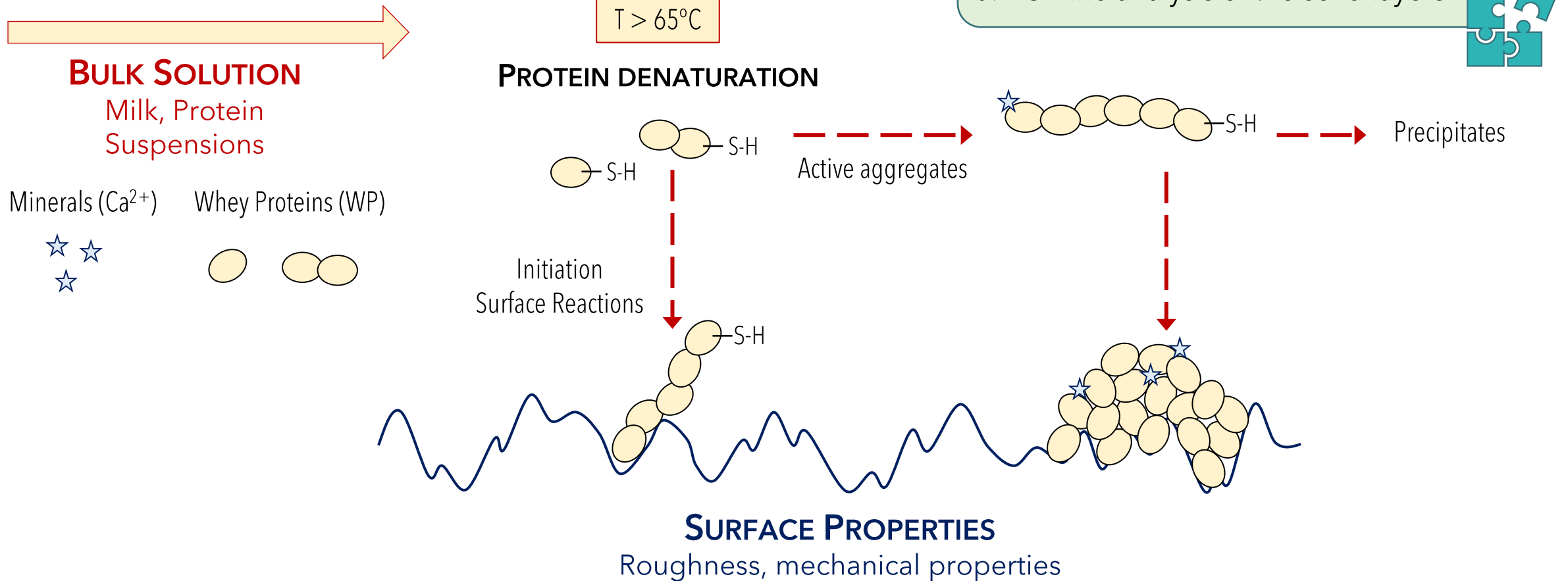
- Constant surface temperature ($T = 45-80^{\circ}\text{C}$)
- Increasing top-to-bottom concentration
- Double interface

> State of the art on fouling mechanisms

Bansal B and Chen X D (2006). Comprehensive Reviews in Food Science and Food Safety.
Visser J and Jeurnink Th J M (1997). Experimental Thermal and Fluid Science.

No direct observation!

1. Equipment like “black boxes”
2. Only global mass/energy balances
3. Offline analysis of the solid layers



Jimenez M, Delaplace G et al. (2013). Journal of Colloid and Interface Science

➤ A microscopic journey: open questions



M. Grostete
Ph.D. Thesis
ENTEVAP Project (2022-25)



Prof. G. Tomaiuolo

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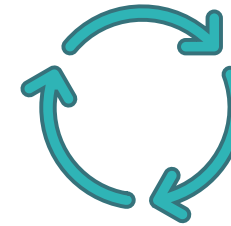
MINIATURIZATION OF THE DAIRY EQUIPMENT CONDITIONS



When?

Driving forces governing WP denaturation/accumulation

- Temperature
- protein concentration
- **shear rate**



Where?

Microscopic dynamics at the **surface** and in the **bulk**
Surficial deposit growth VS aggregate formation

How?

Nature of **protein/surface interactions**

- Chemical adsorption
- Short-range attractions

> Deposit formation: an alternative scenario



No fouling observed for $T < 65^{\circ}\text{C}$

Jeurnink Th J M, Walstra P, de Kruif C G (1996). Netherlands Milk and Dairy Journal.

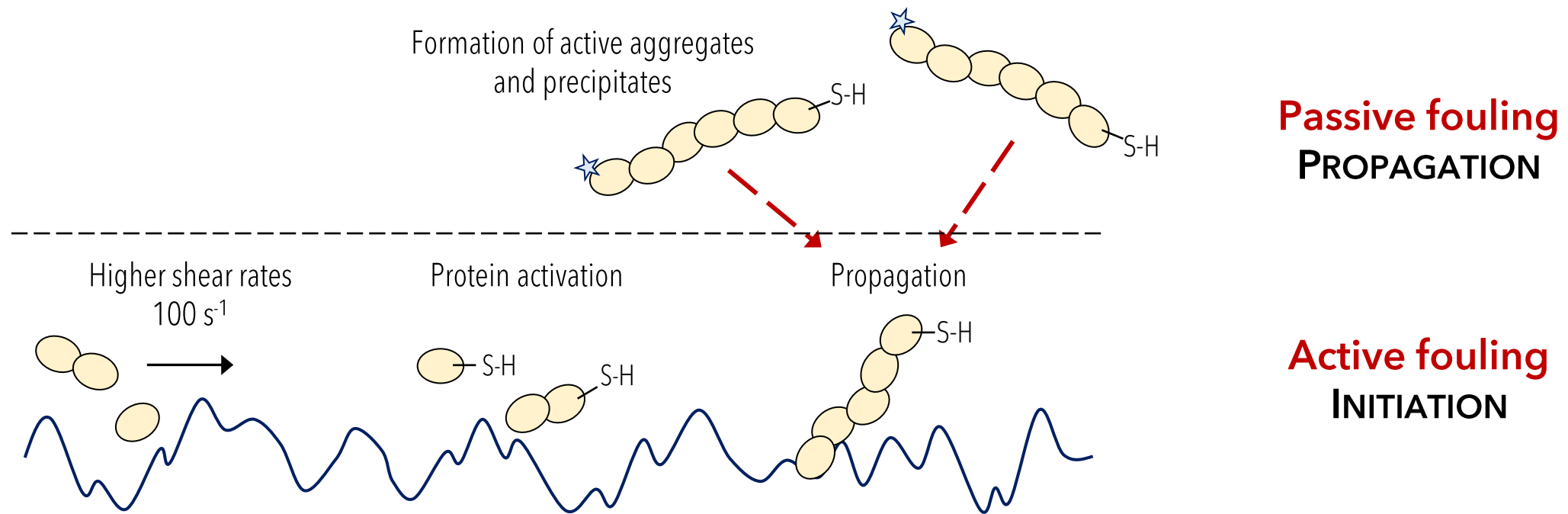
Absence of protein denaturation



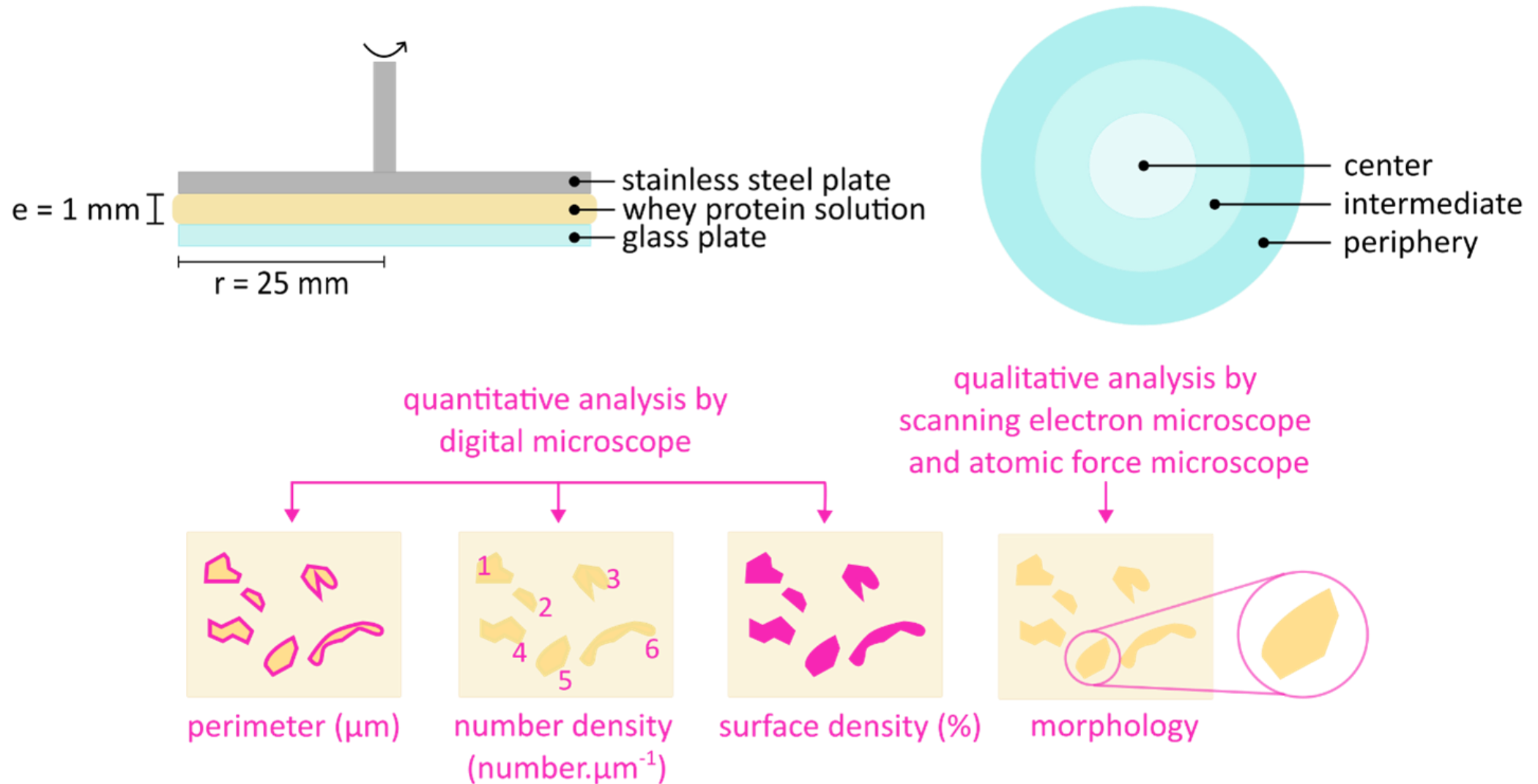
Deposit development even at $T=45^{\circ}\text{C}$ in evaporators



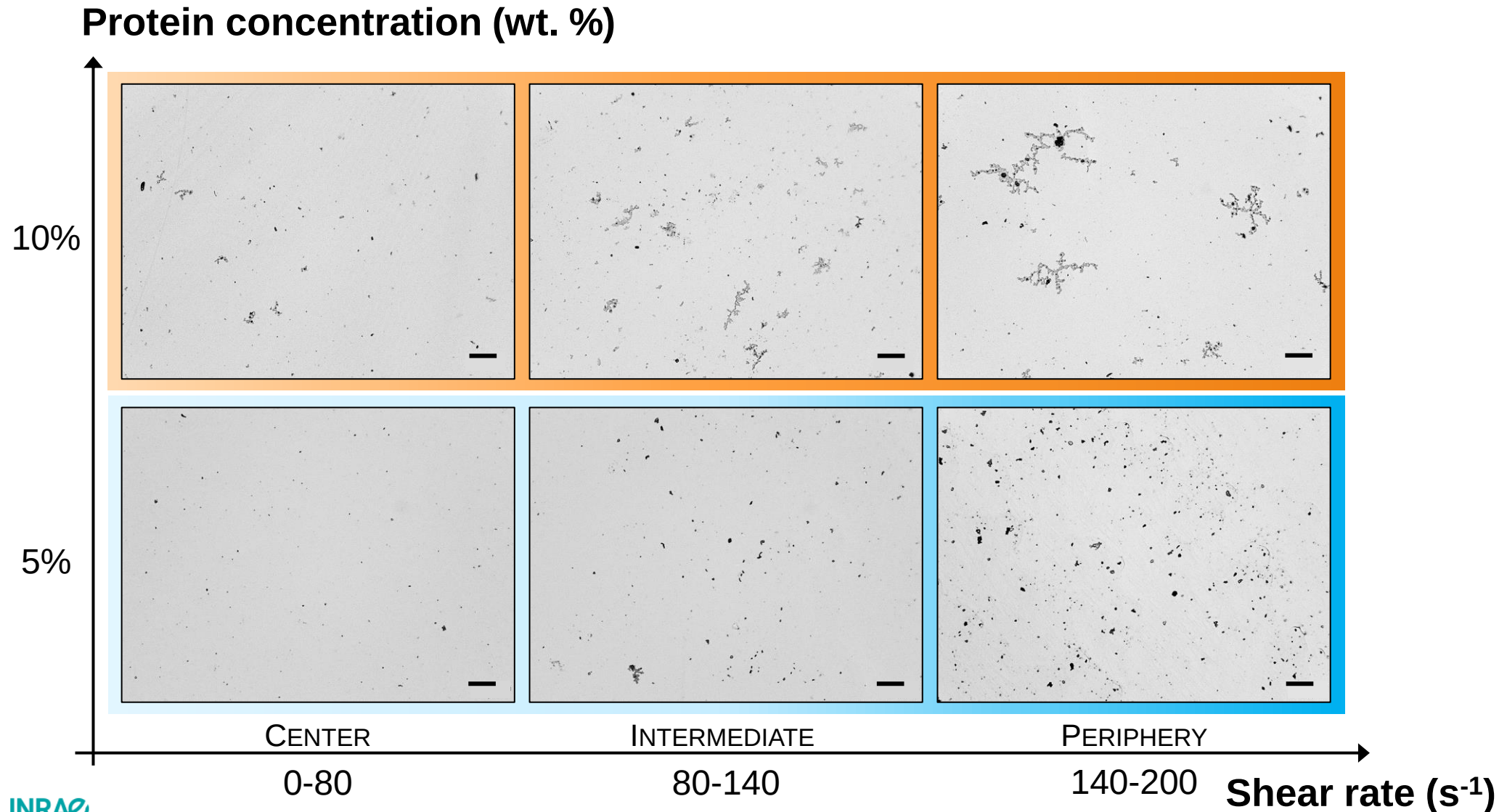
DOUBLE IMPACT OF TEMPERATURE AND SHEAR RATE



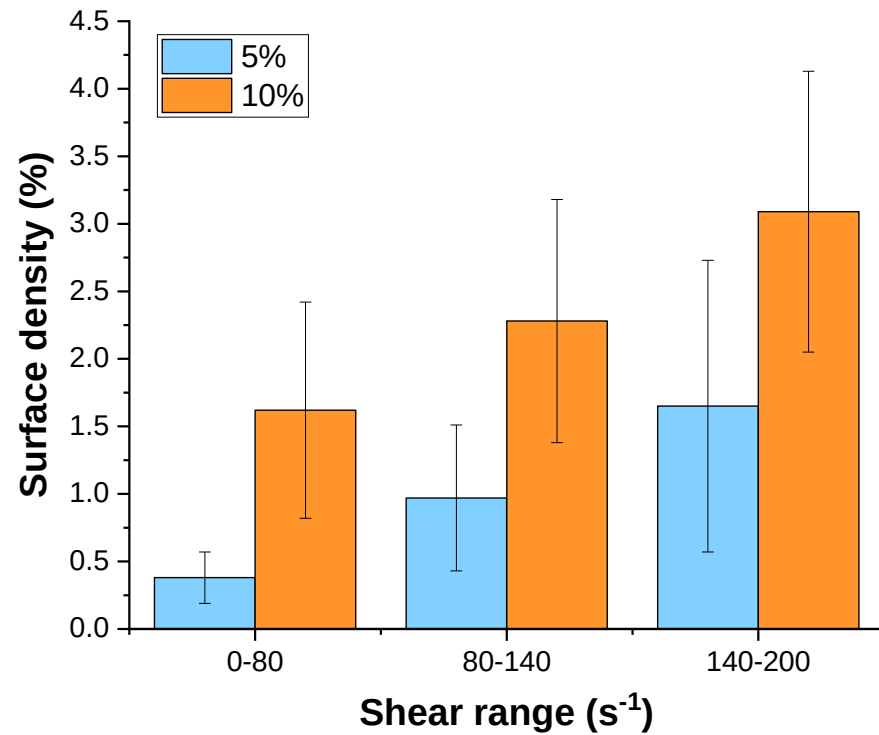
➤ Rheofluidics: a simple and flexible strategy



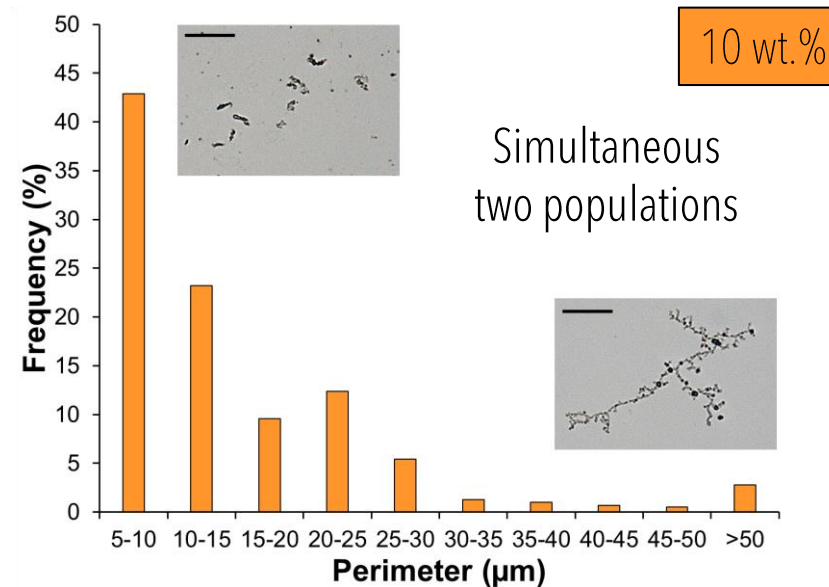
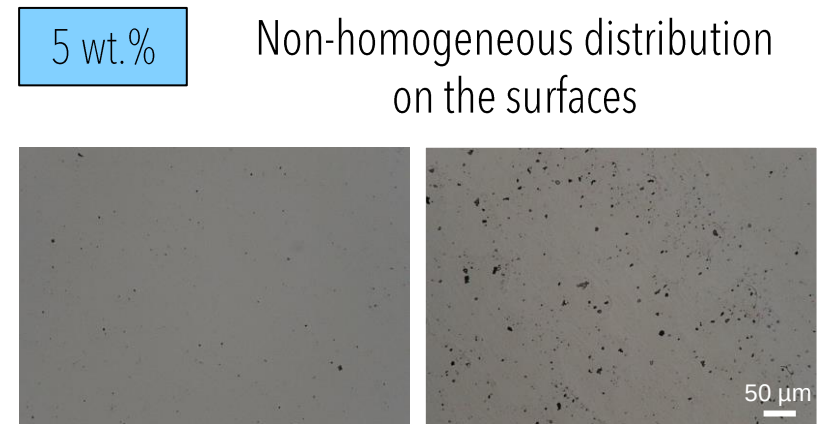
➤ Qualitative observation of WP surficial deposits



➤ Quantification of the shear impact



High standard deviations
because of dynamics of
protein accumulation



Grostete et al. (2024), Int J of Biological Macromolecules.

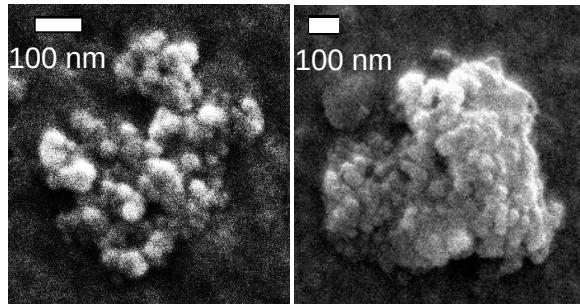


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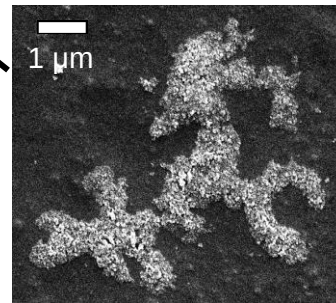
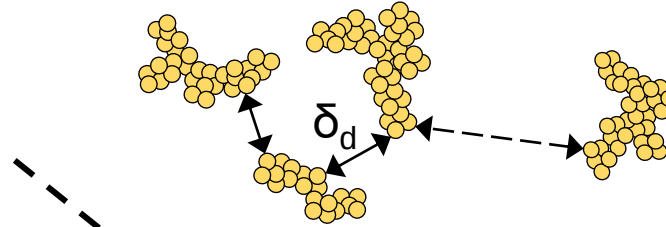
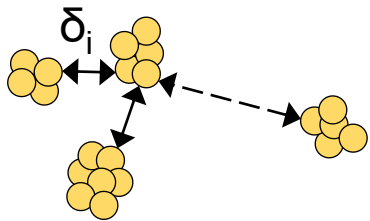
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➤ Hypothesis on the stages of protein accumulation



INITIATION POINTS



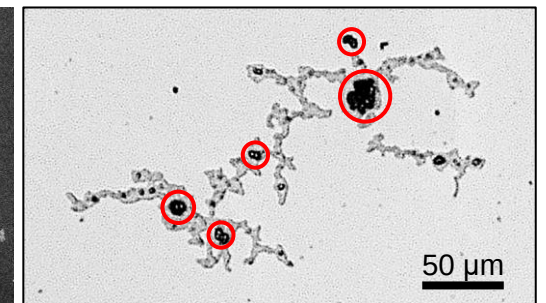
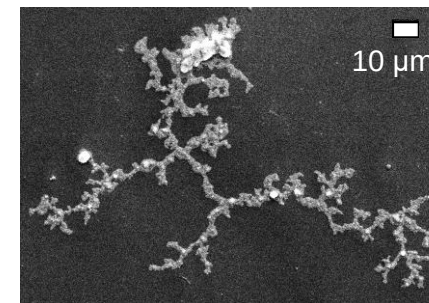
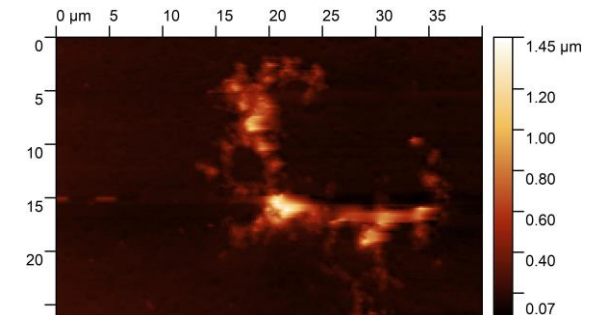
PRIMARY DEPOSITS

- Thermal denaturation and adsorption ✓
- Role of the shear stress ✗

TIME AND DISTANCE ARE CRUCIAL PARAMETERS

- Interconnection of primary deposits
- Structure complexification

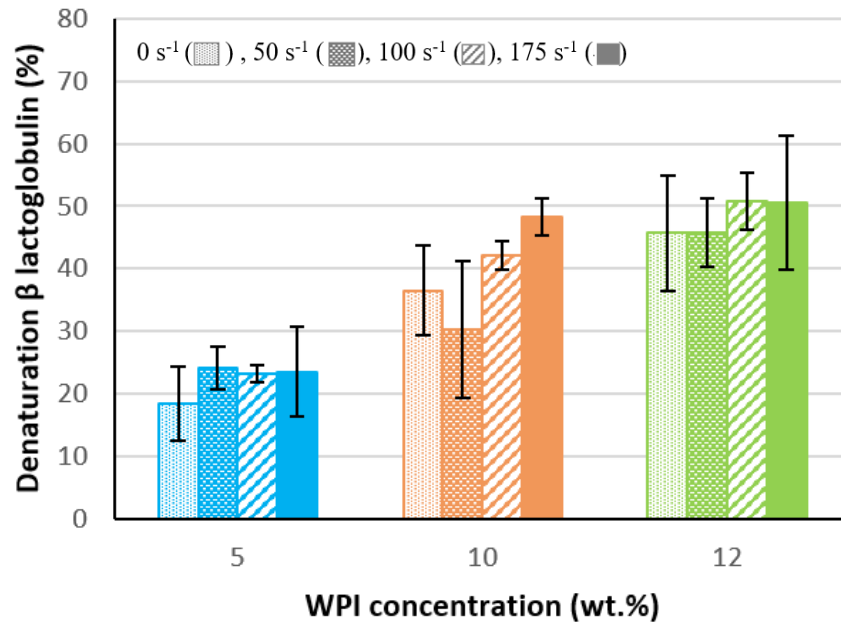
PHYSICO-CHEMICAL NATURE OF THE DEPOSITS



BRANCHED STRUCTURES

➤ What happens in the “bulk”?

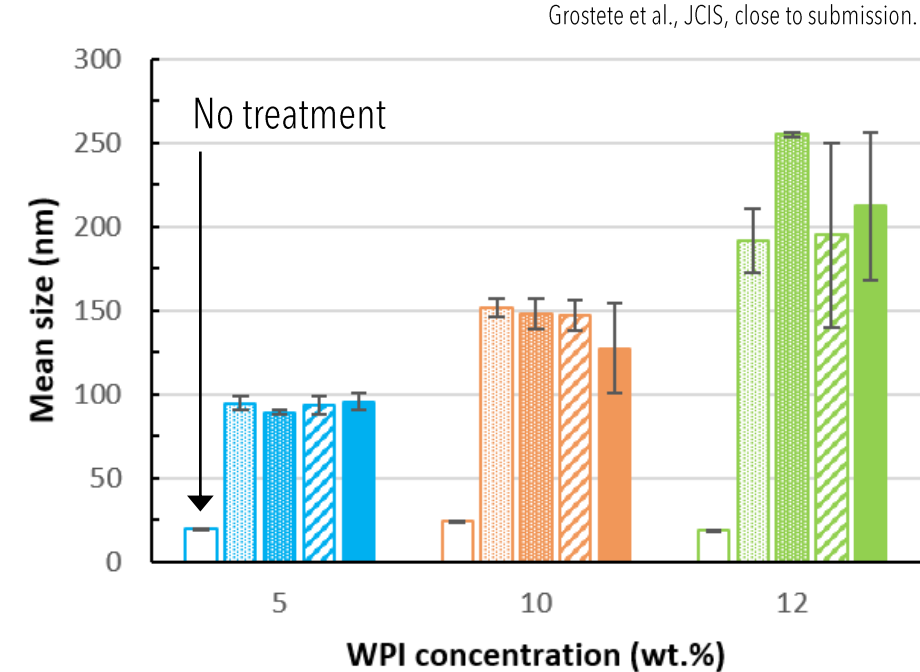
Tests by con-and-plate rheometers



Denaturation in the bulk governed by thermal effect and protein concentration



Impact on protein-protein interactions and WP aggregate formation



Submicronic WP aggregates predominant in the solutions (confirmed by microscopy observations)



ENHANCED DEPOSIT PROPAGATION
DOES IT EXCLUDE SHEAR-INDUCED DENATURATION?

> Conclusions

Surface

- Increasing shear stresses enhance deposit formation in terms of number (dilute conditions) and shape complexification (concentrate conditions)
- Evident effect of the shear when combined with thermal one
- Deposit formation possibly due to both chemical and physical interactions next the surface

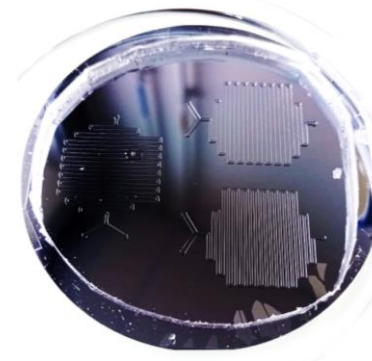
Bulk

- No impact of the shear on protein denaturation and aggregate mean size
- Combined effect of temperature and protein concentration

> What's next?

Direct observation of the phenomenon

Microfluidics



➤ Preliminary results and exponential difficulties

Visit the poster of Margot

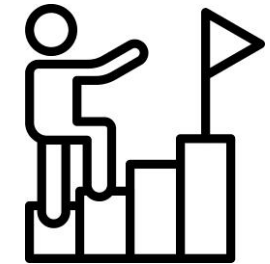


Experimental challenges

- *Repeatability* of the experiments (defects, bubble formation)
- *Control* of the temperature (device and solution)
- *Estimation* of the shear (rheometer vs wall shear)

DEEPENED INVESTIGATION LEADS TO MORE COMPLEX QUESTIONS

- Shear intensity and shearing time
- Absolute temperature and ΔT
- Air-liquid interfaces



Grazie a tutti per la vostra attenzione Please, bring me back home!



Risultati per **Rennes, Francia**

