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Interfacial Polymerization kinetics: new insights on film formation using in-situ microscopy and particle-tracking

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Water & Energy Technologies Laboratory

Water & Energy Technologies Laboratory

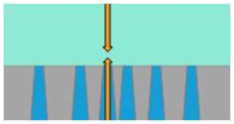
Introduction

Interfacial Polymerization (IP)

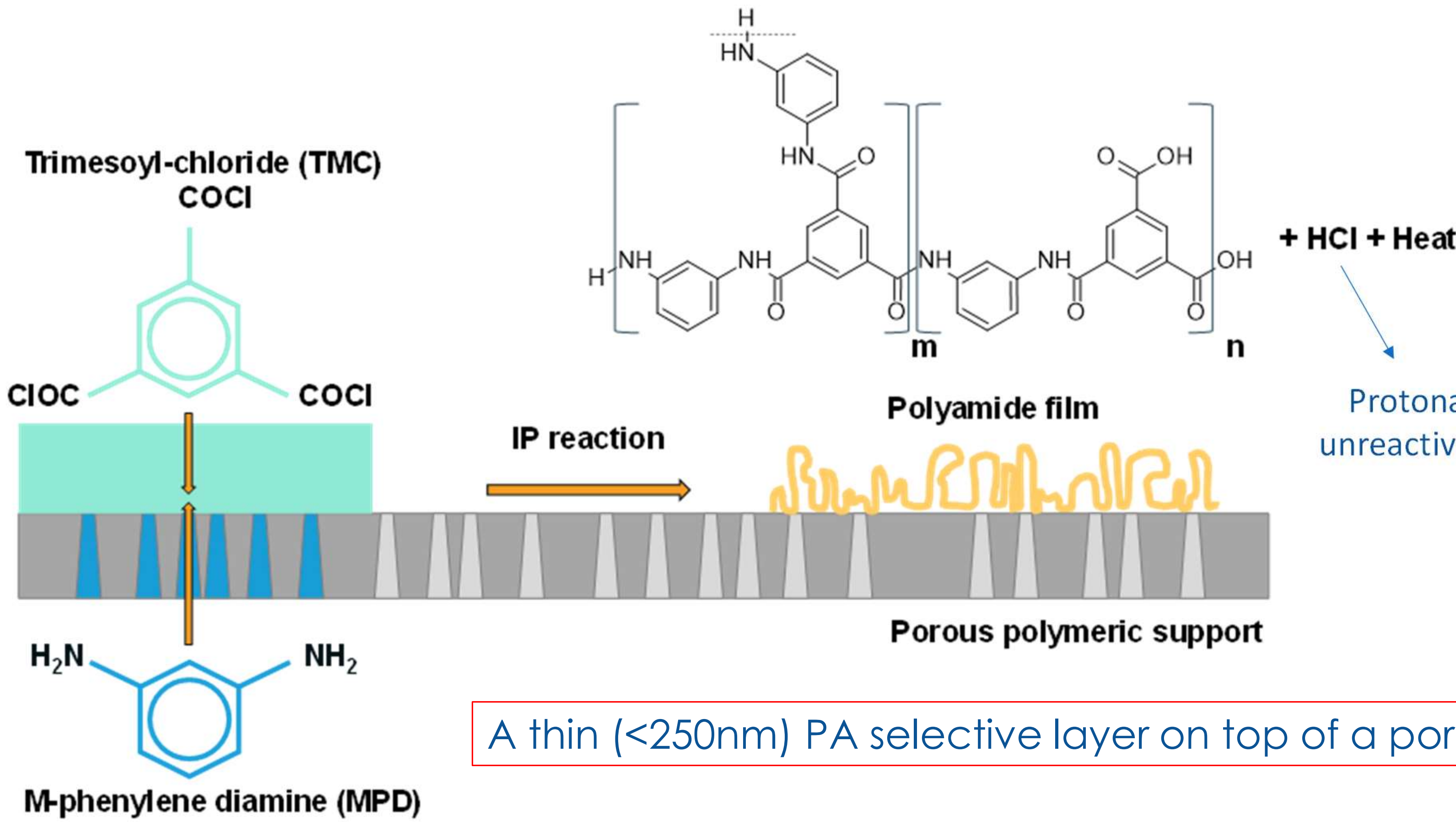
Introduction

Interfacial Polymerization (IP)

- A polycondensation reaction occurs at the interface



IP Interfacial Polymerization



Protonated MPD unreactive with TMC

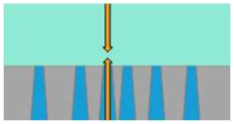
A thin (<250nm) PA selective layer on top of a porous support

Nulens and Ben Zvi, *JMS* (2022)

Introduction

Interfacial Polymerization (IP)

- A polycondensation reaction occurs at the interface



- IP is used to fabricate thin-film composite (TFC) polyamide (PA) membranes first synthesized in late 70s by Cadotte et al.

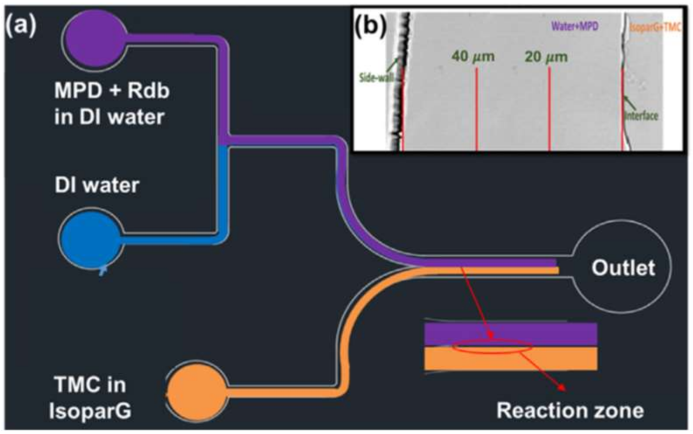
- State-of-the-art desalination by reverse osmosis (RO) **>99% rejection**

Introduction

How can we understand more about IP?

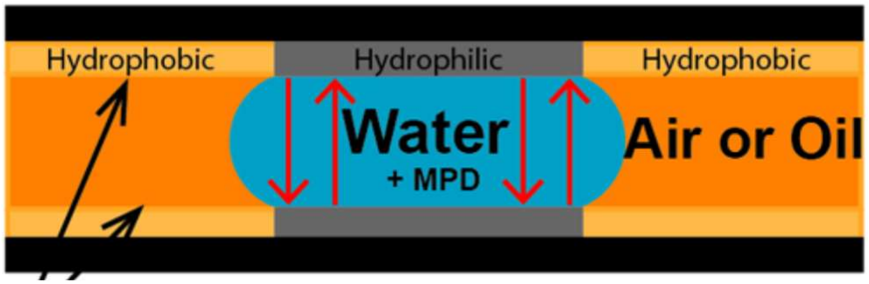
In-situ monitoring – insight of reaction kinetics

Heat transfer



Ukrainsky and Ramon, *JMS* (2018)

Mass transfer



Nowbahar et al., *J. Am. Chem. Soc.* (2018)

The product of IP:

Crumpled polyamide film

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Crumpled polyamide film

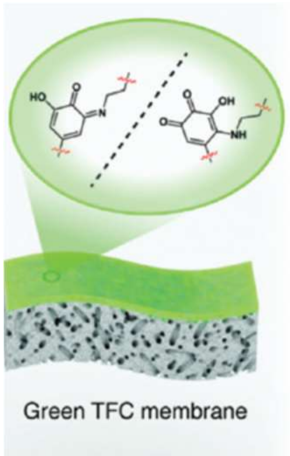
Why ?

Motivation

Why ?

Synthesis —— Morphology —— Performance

- ✓ Improve existing membranes
- ✓ Move towards 'green materials'



Park et al., Green Chem. 2021

The product of IP:

Crumpled polyamide film

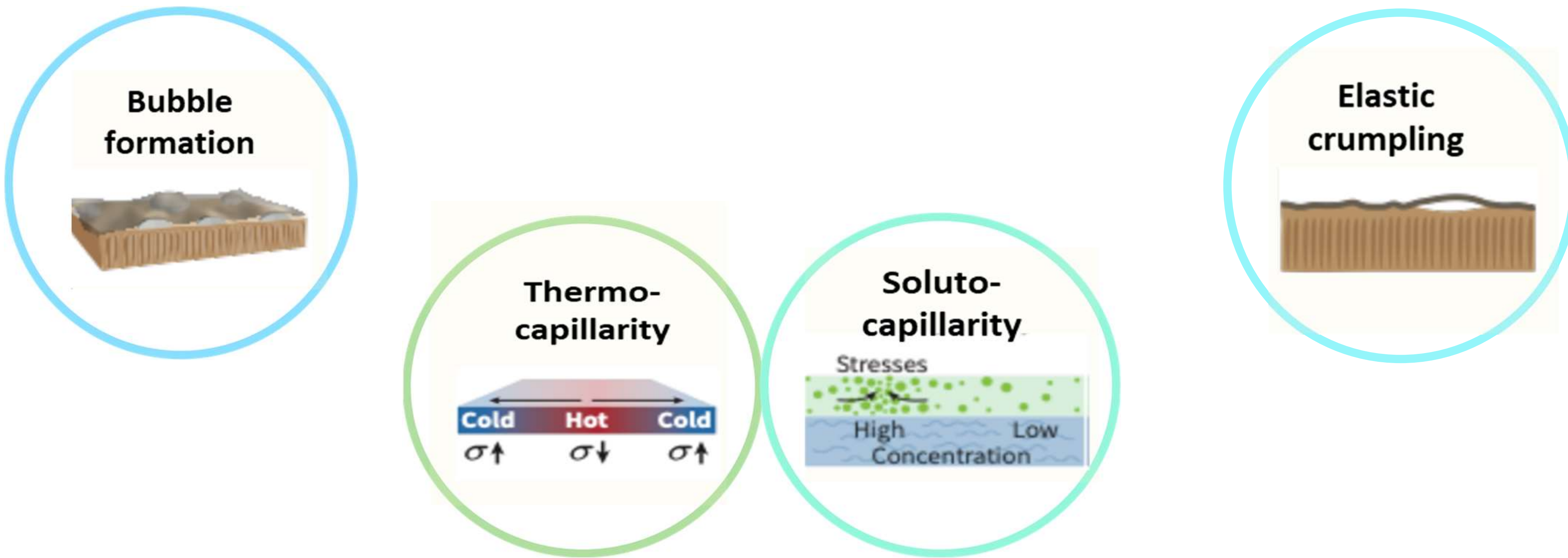
Why ?

How ?

Hypothesis

How ?

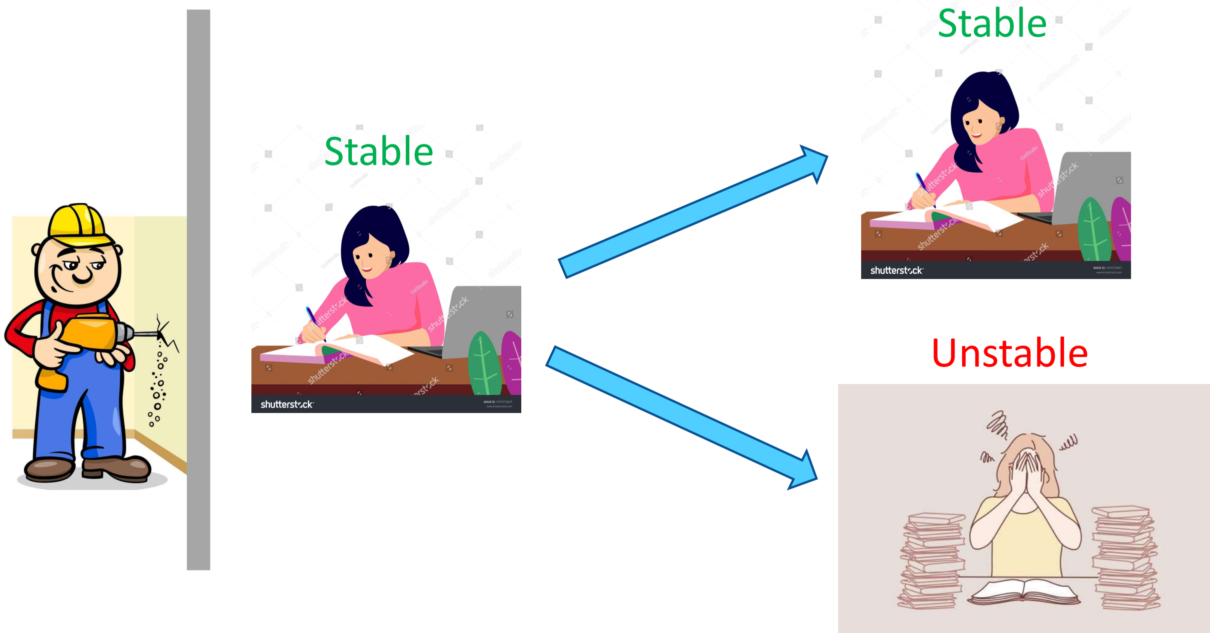
Instability mechanisms



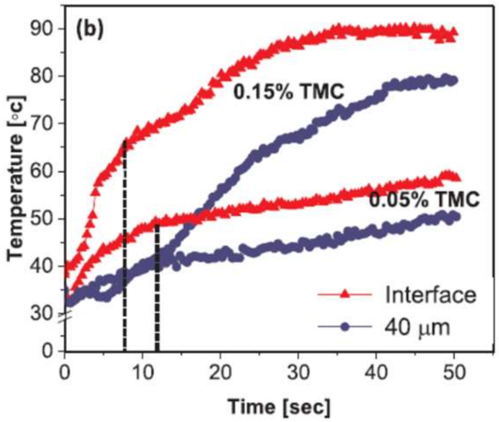
Freger and Ramon, *Prog. Polym. Sci.* (2021)

Instability

The **inability** of a system to **sustain** itself against small **perturbations**.



Transition from **stable** to **unstable**: e.g., laminar to turbulent flow

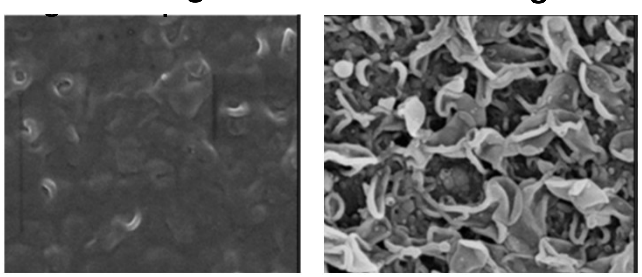


Ukrainsky and Ramon, *JMS* (2018)

Local overheating in the reaction zone

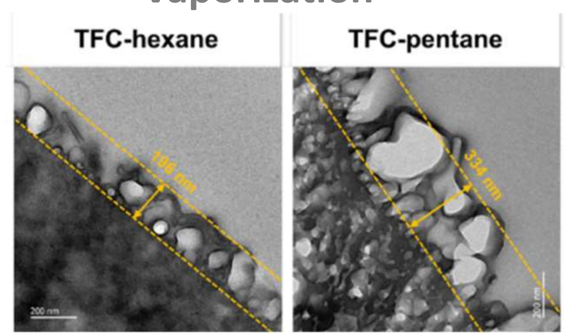
Nanobubbling

No soluble gasses | With soluble gasses



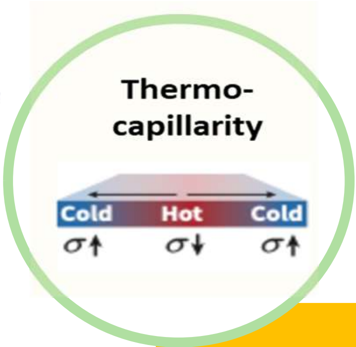
Ma et al., *Environ. Sci. Technol. Lett.* (2018)

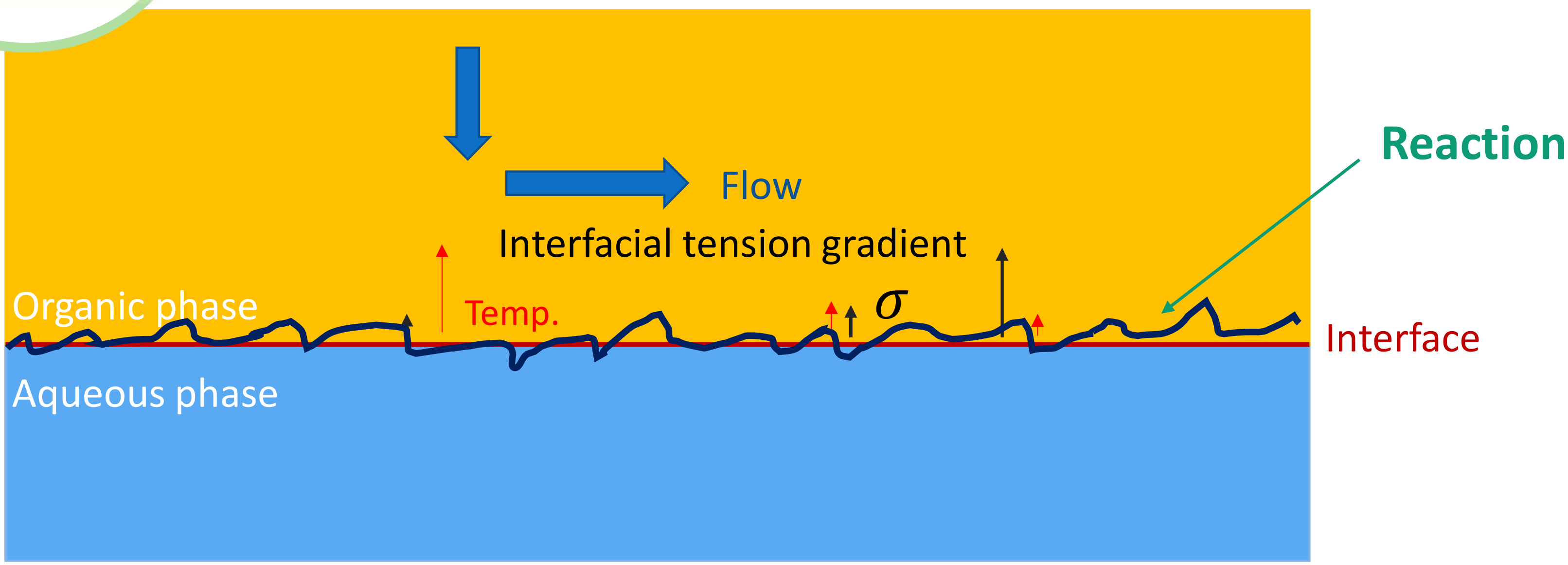
Vaporization



Peng et al., *JMS* (2021)

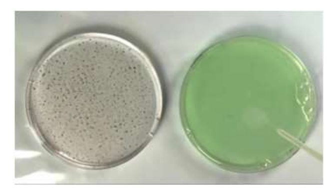
IP system



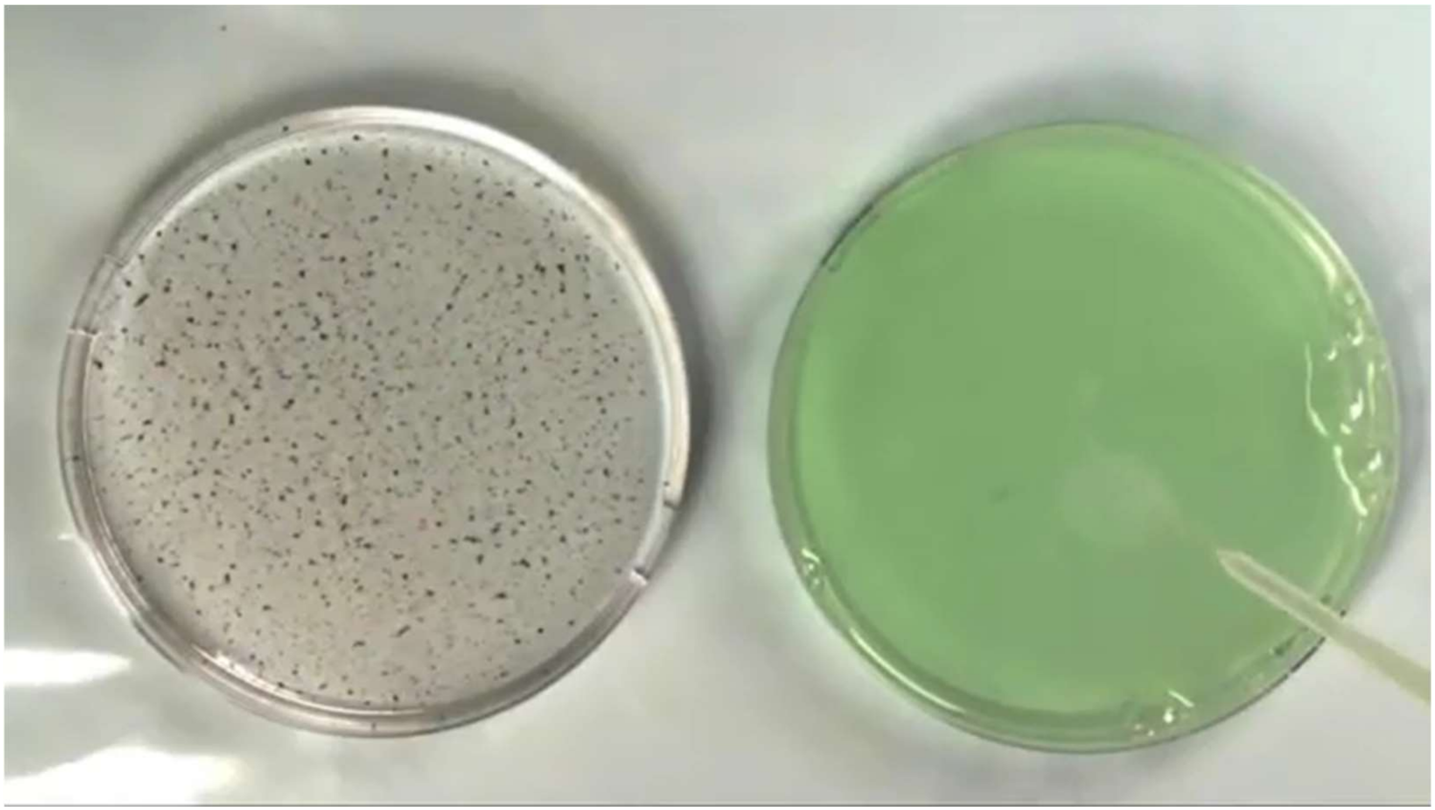


Gradients in interfacial tension drive a flow:

Marangoni flow



Water & Energy Technologies Laboratory



https://www.youtube.com/watch?v=y0WRJtXvpSo

Hypothesis

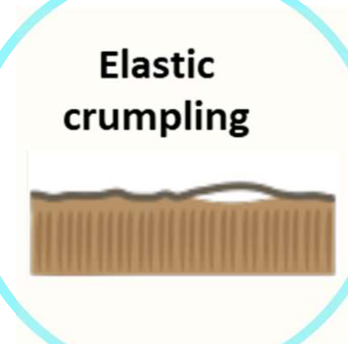
How ?

During film formation

After film formation

Instability= flow in IP system

Film Crumpling



Wrinkling of the formed film due to different elastic properties between the film and the support

Loc

causes 'degassing'

Freger and Ramon, *Prog. Polym. Sci.* (2021)

The product:

Crumpled polyamide film

Journal of Membrane Science
Available online 10 May 2022, 120593
In Press, Journal Pre-proof

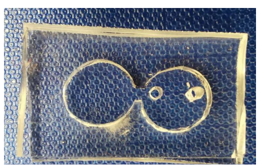
Re-thinking polyamide thin film formation: How does interfacial destabilization dictate film morphology?

Ines Nulens [a, 1], Adi Ben-Zvi [b, c, 1], Ivo F.J. Vankelecom [a], Guy Z. Ramon [b, c, d]

How ?

Methods

How can we observe a **flow** in IP ?



Microfluidic device

Aqueous phase: fluorescent particles (1μm) + MPD

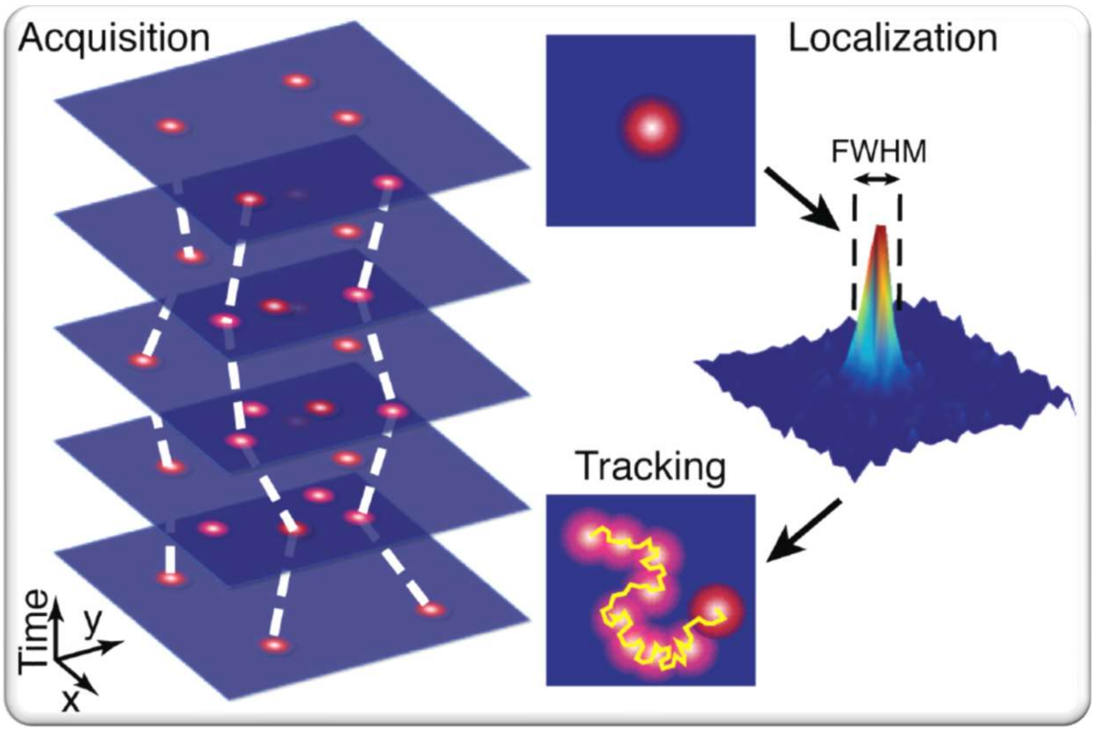
Organic phase: Isopar-G + TMC

Confocal Microscopy

Videos of 2D image over time

Methods

Particle Tracking



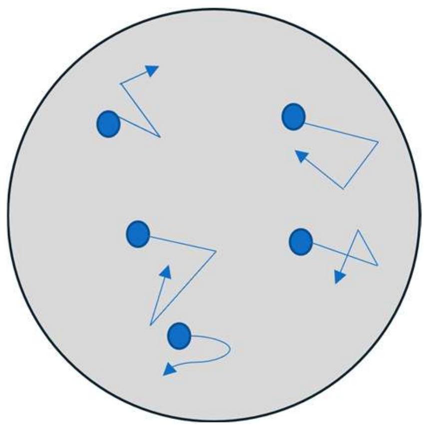
Manzo et al., Rep. on Prog. in Phys. (2015)

Acquisition of the displacement using confocal microscopy

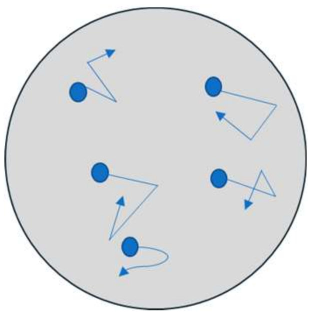
What do we expect to see?

What do we expect to see?

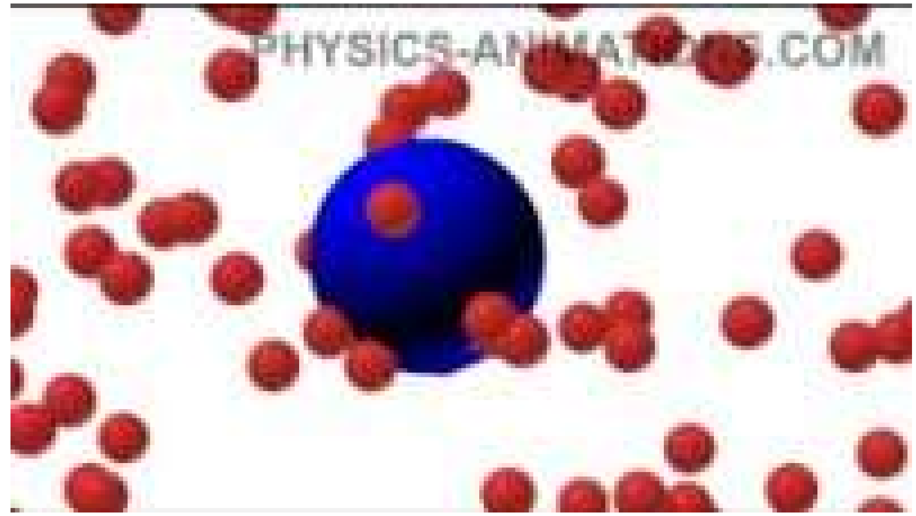
Random motion (Brownian)



Brownian motion



- No bulk flow.
- The motion is thermal-driven.



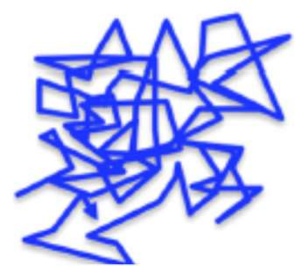
<u>Stokes-Einstein relation:</u>

$$D = \frac{k_\mathrm{B}T}{6\pi\,\eta\,r}$$

$$\frac{\text{Thermal energy}}{\text{Viscous friction}}$$

k_B Boltzmann constant
T temperature
η dynamic viscosity
r radius of particle

Trajectories:



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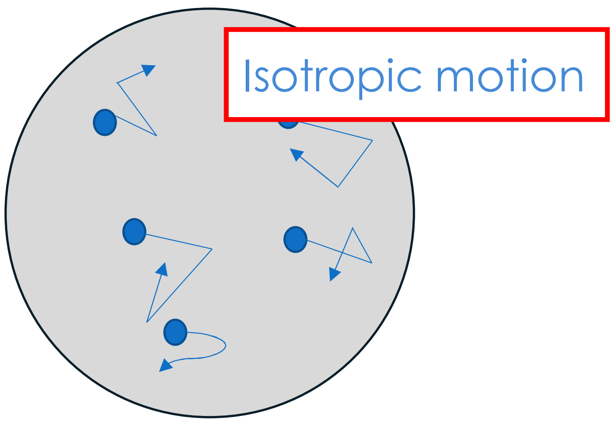

- No bulk flow.
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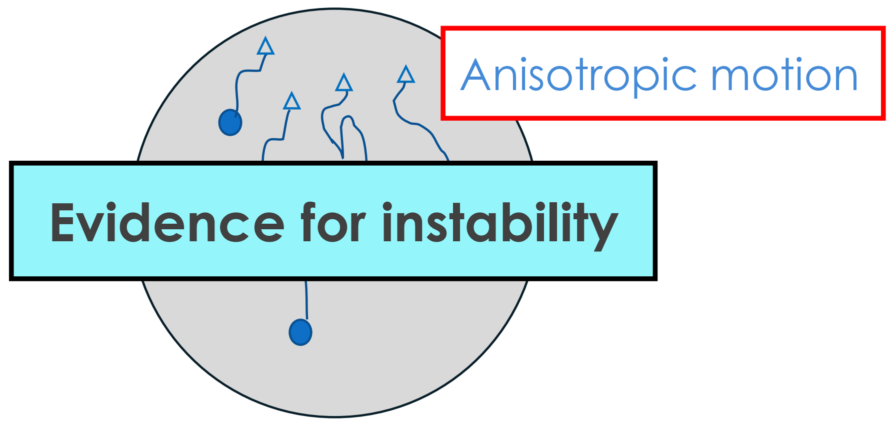
Directed motion

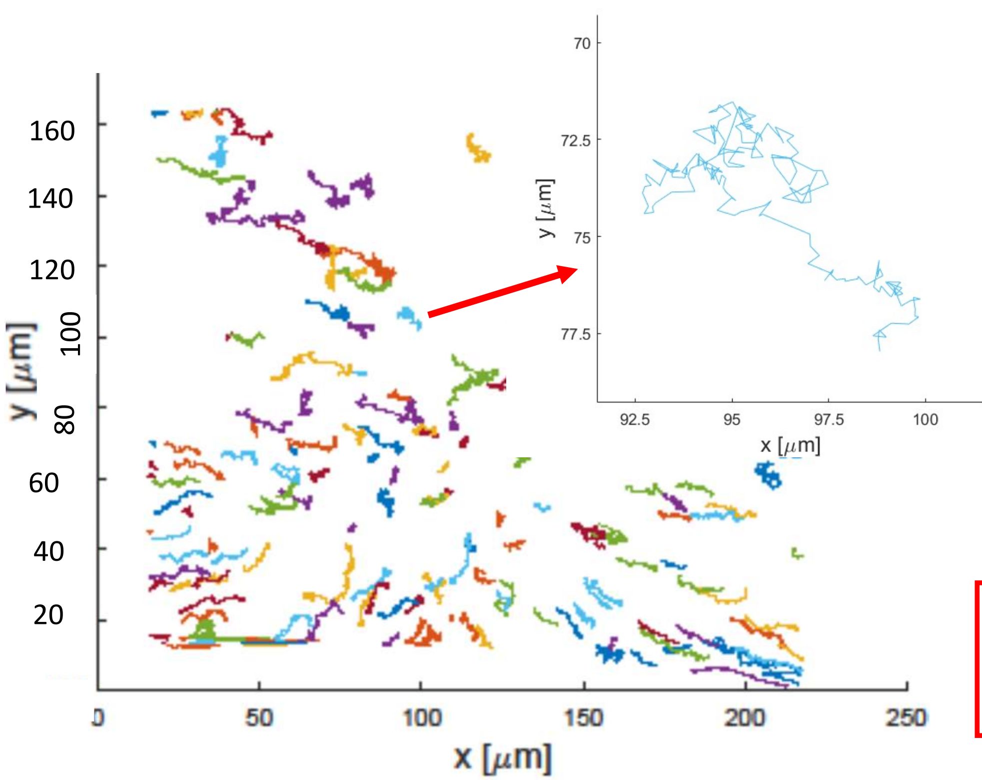


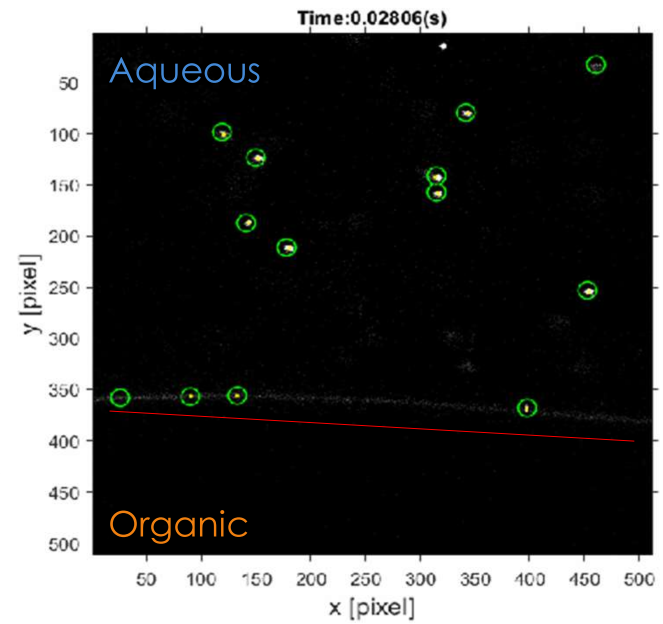
- Particles act as tracers that move with the bulk.
- **Brownian + bulk directed motion**

Results

Observed trajectories

<u>Blank</u> DW; Isopar-G





- Non-directed motion of particles
- The motion has Brownian behavior

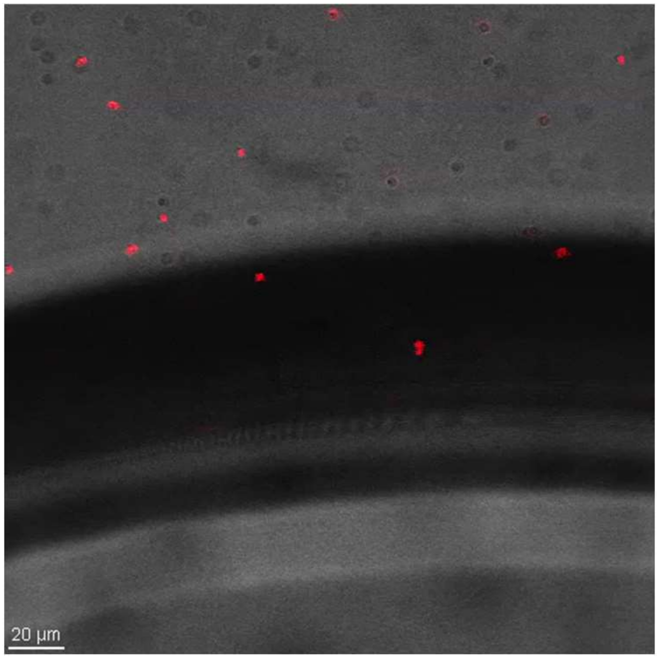
Results

Videos

Low concentrations:

DW+ 0.02% MPD

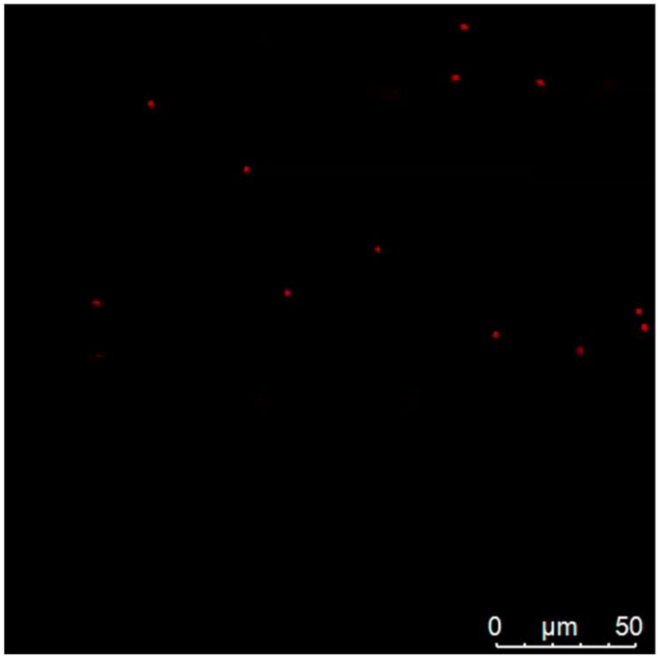
Isopar-G + 0.001% TMC



High concentrations:

DW+ 2% MPD

Isopar-G + 0.15% TMC



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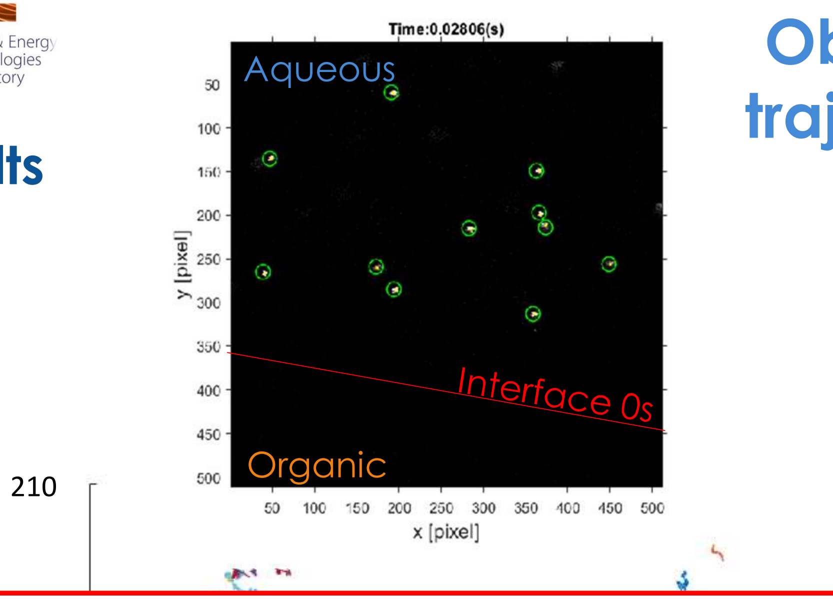
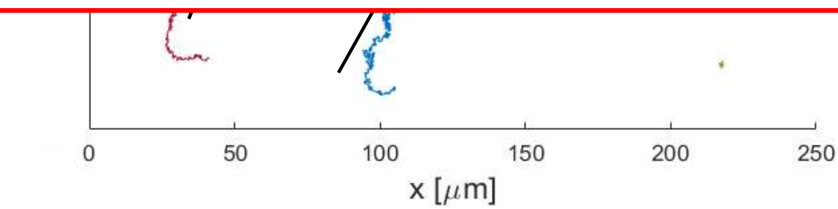
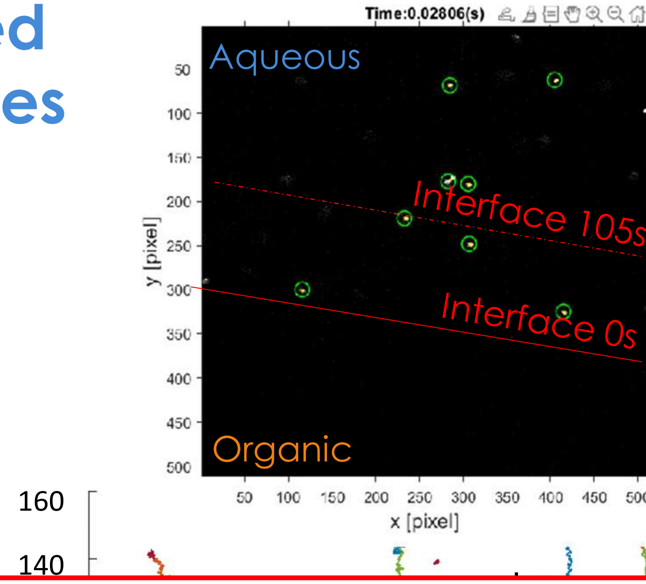


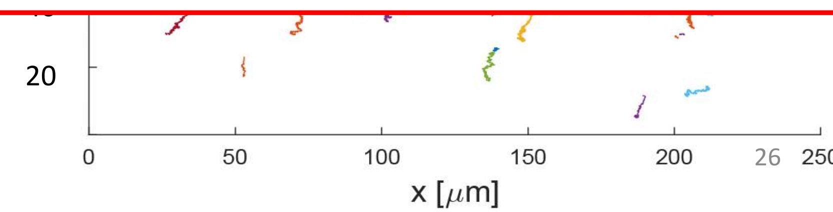
- More directed motion of particles than the blank
- The particles that are closer to the interface have more directed flow



High concentrations



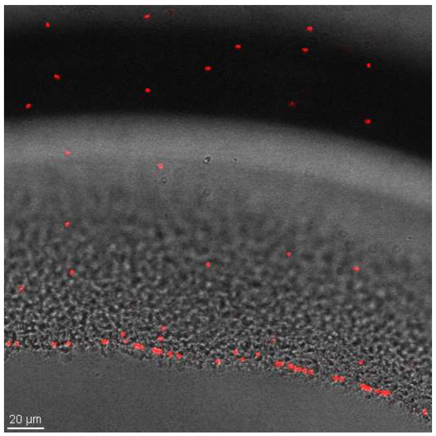
- Directed motion of particles towards the interface
- The particles reach the interface and remain there



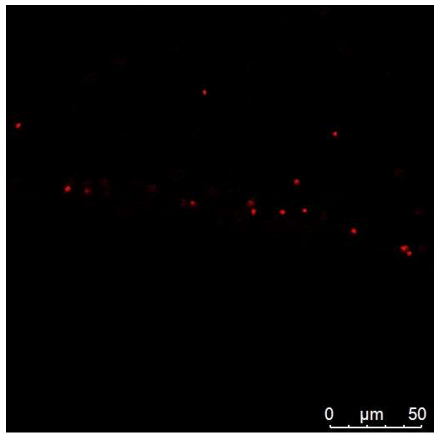
Results

Images **High concentrations**

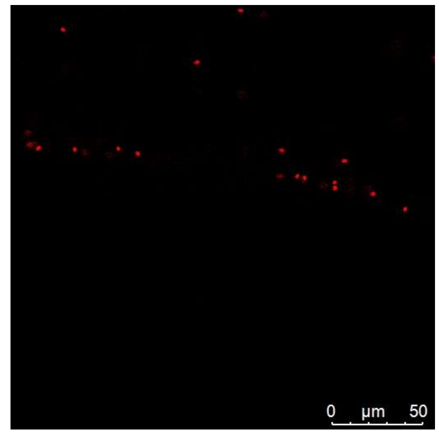
Hight 0



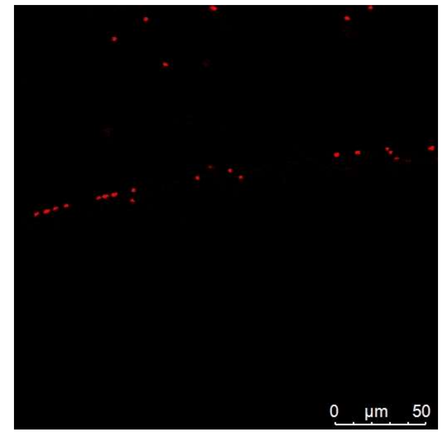
Hight 50 µm



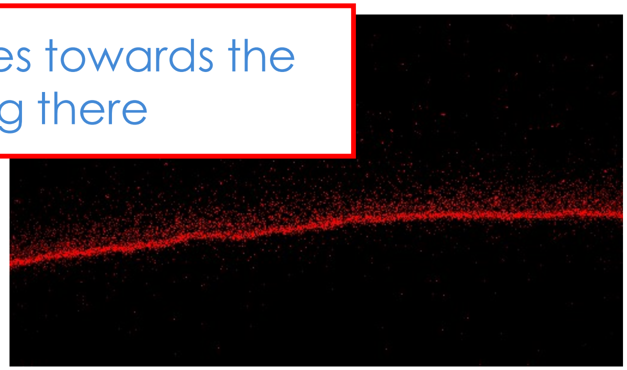
Hight 100 µm



Hight 450 µm



- A movement of particles towards the interface and remaining there



Hight 0
0.1 µm particles

Conclusions

- Different motion behaviors between blank, low, and high monomer concentrations.
- At higher monomer concentrations a directed motion was observed.
- At high monomer concentrations there is a motion towards the interface.
- Tracking particles provides us with new insights about IP.

Future work:

- Data analysis.

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Future work:

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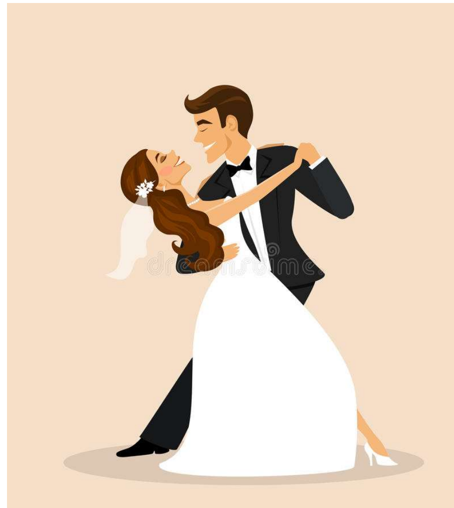
- The other side of the picture.



?

Aqueous phase

Organic phase

interface

Conclusions

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- At higher monomer concentrations a directed motion was observed.
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Future work:

- Data analysis.
- The other side of the picture. 
- Kinetics of film formation?

Acknowledgements

משרד התשתיות הלאומיות, האנרגיה והמים
www.energy.gov.il

BARD

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Thank you for Listening ☺