Nanoparticle Design for Removal of Organic and Inorganic Residues from Surfaces

(Enhanced Oil Recovery, Lubrication, Detergency, Anti-microbial)

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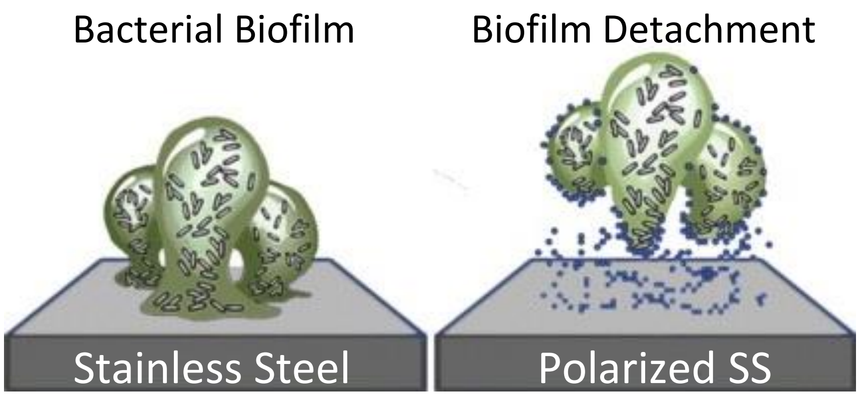
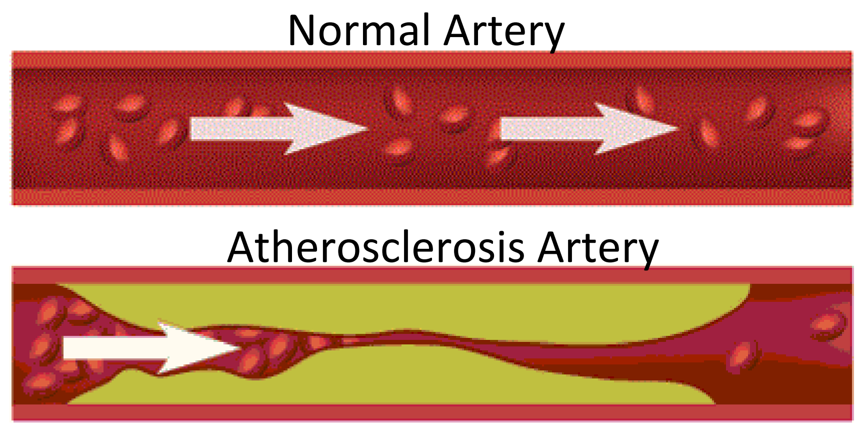
Potential Applications

Microbes Removal



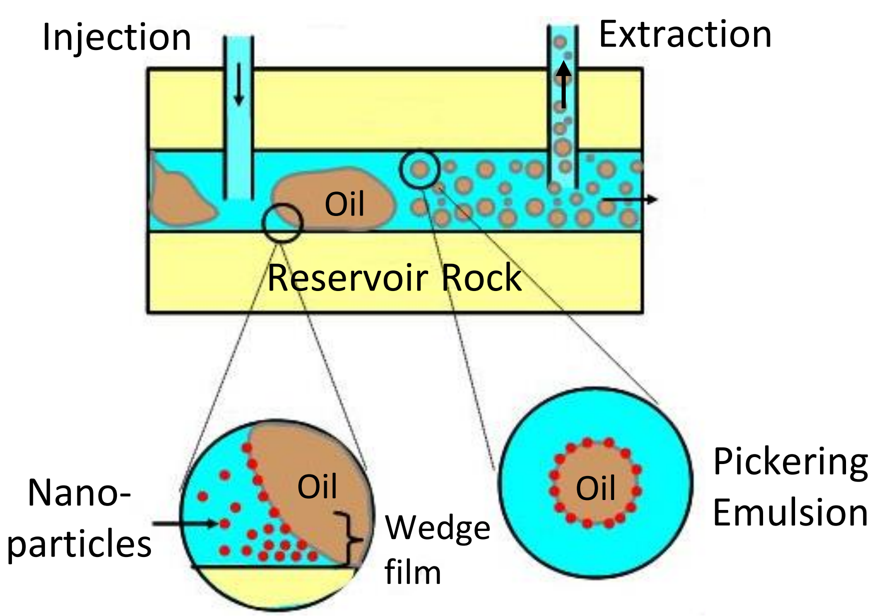
doi.org/10.1016/j.colsurfb.2014.02.021

Medical Application



clinicaladvisor.com/slideshow/slides/hyperlipidemia-coronary-heart-disease/

Enhanced Oil Recovery



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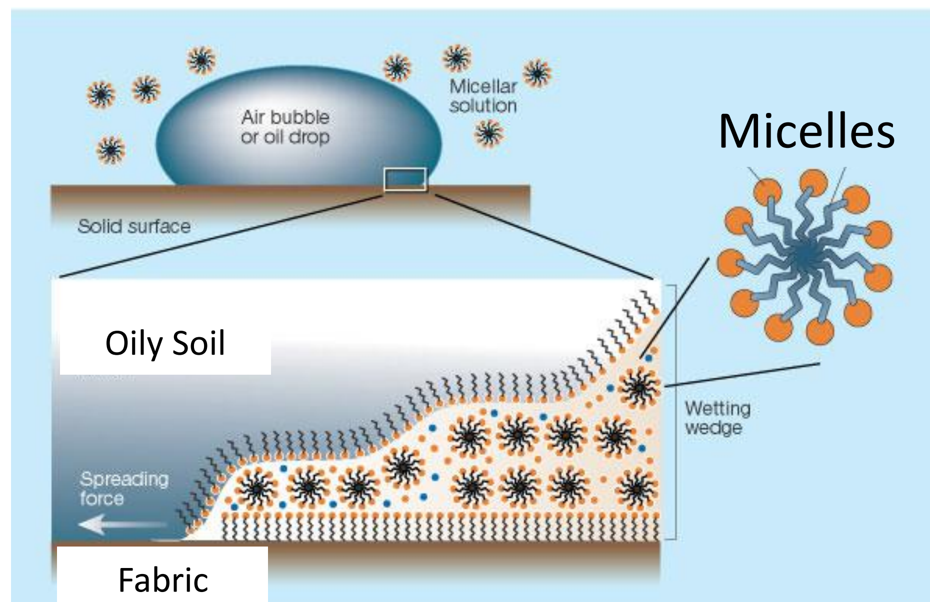
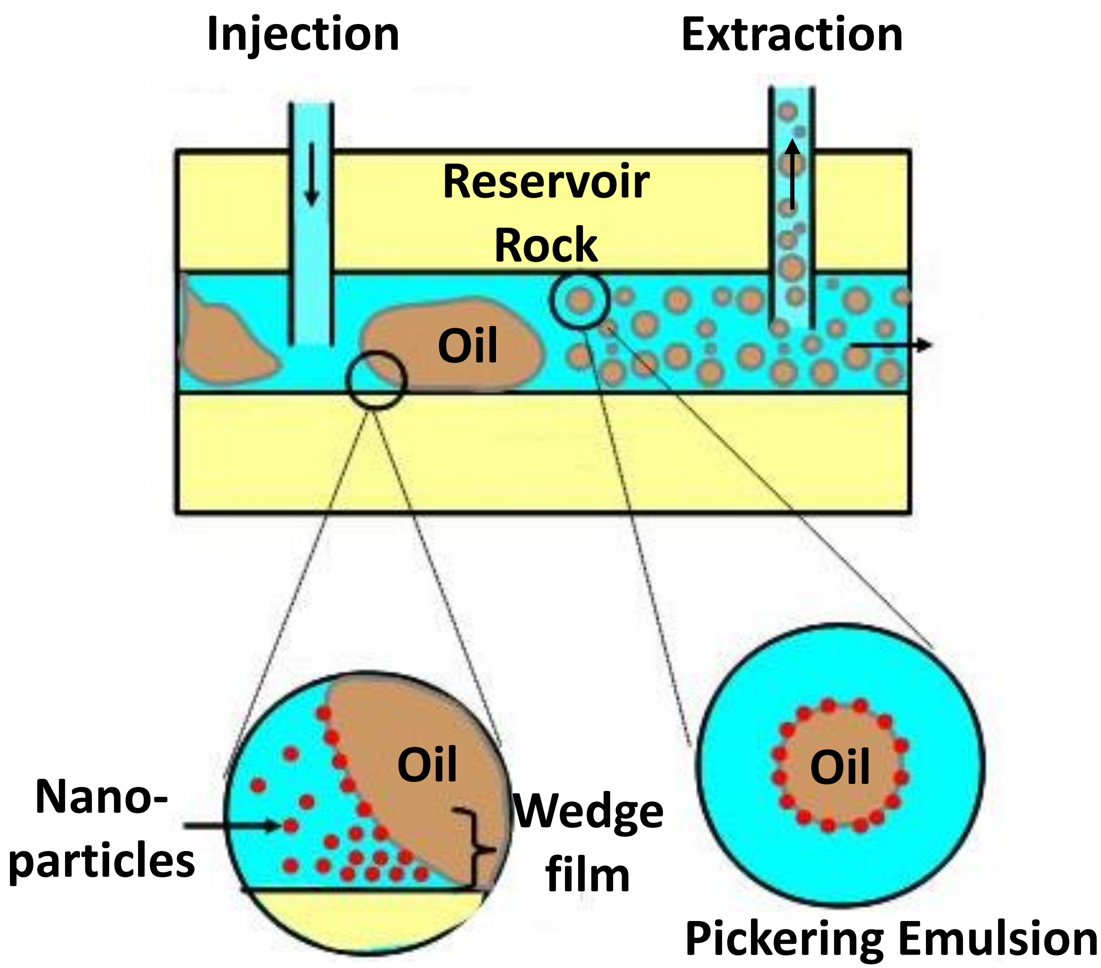
Detergency



Chaudhury, Manoj K. *Nature* 423.6936 (2003): 131.

Background – nanoparticle mediated EOR



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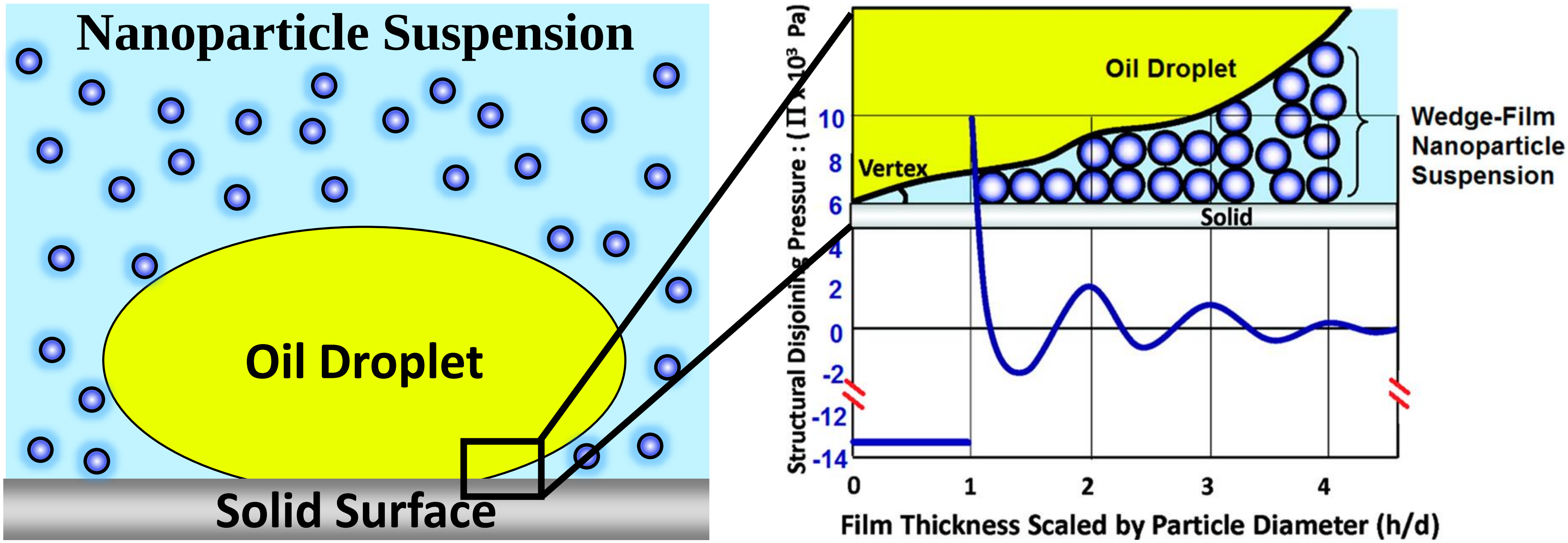
1. Injection of dispersed nanoparticles
2. Disjoining of the crude oil from reservoir rock.
3. Emulsification and stabilization of the crude oil (Pickering emulsion)
4. Extraction and post treatment of the emulsion

- How could nanoparticles detach (uncouple) the crude oil from reservoir rock? What is unique about this process?

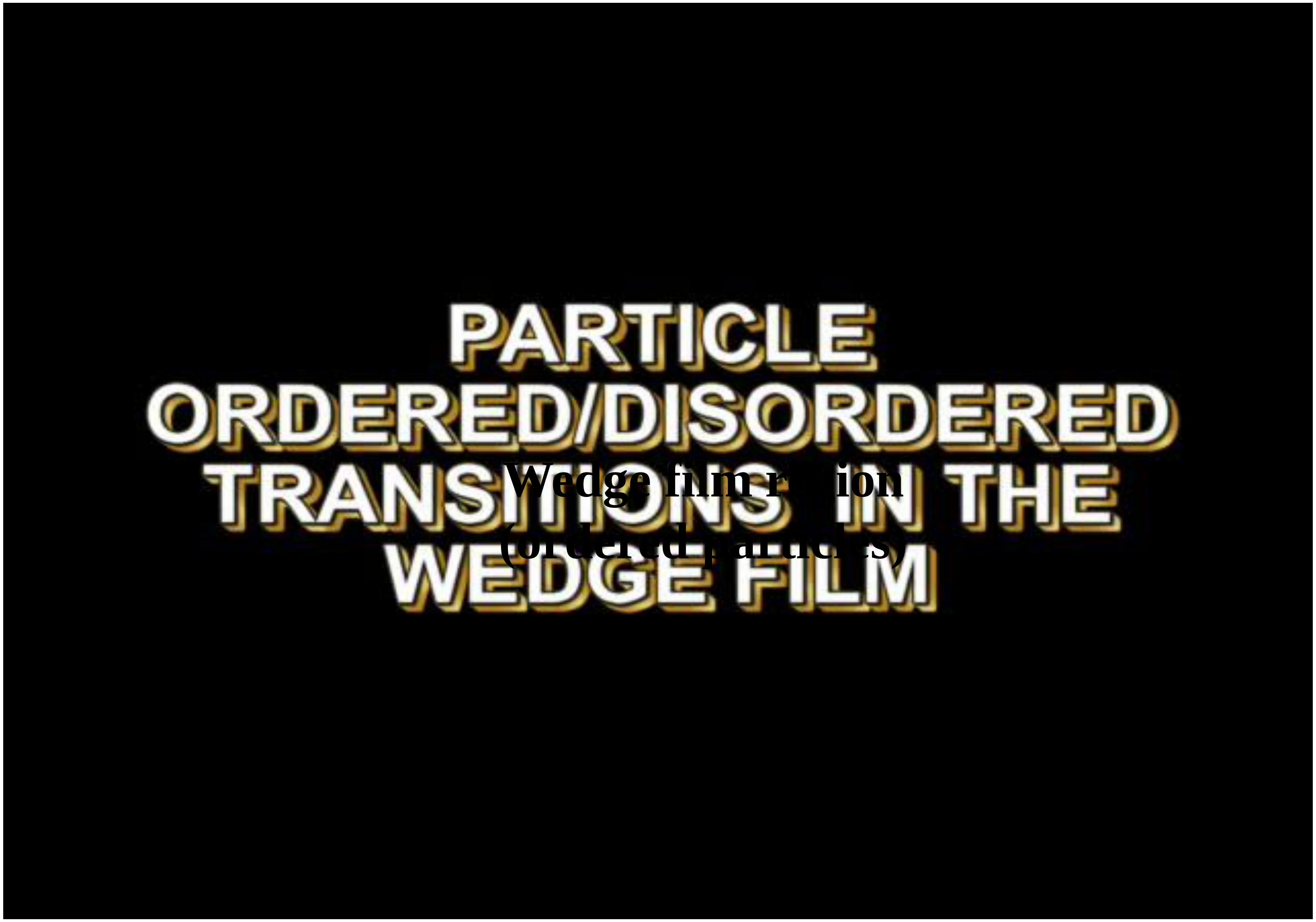
Nanoparticle mediated detachment of oil droplet from surfaces



Wasan, Darsh, Alex Nikolov, and Kirti Kondiparty. Current Opinion in Colloid & Interface Science 16.4 (2011): 344-349.

- Disorder to order transformation of nanoparticles structuring from bulk to confined spaces (wedge film region).
- The orderly structured colloids could create high disjoining pressure in the confined space, which enhances the detachment of remnant oil from the reservoir rock.
- Results in the literature shows that 55% crude oil can be recovered from sandstone by using suspension of silica nanoparticles, compared to 2% by the water alone.

Observing the Particle Structuring in Wedge Film

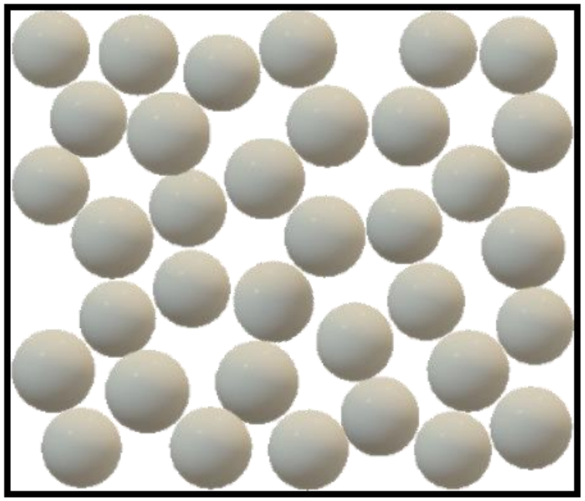


Wasan, Darsh T., and Alex D. Nikolov. "Spreading of nanofluids on solids." *Nature* 423.6936 (2003): 156.

- **Particle structuring in wedge film region could enhance the spreading of nanofluid by increasing disjoining pressure.**

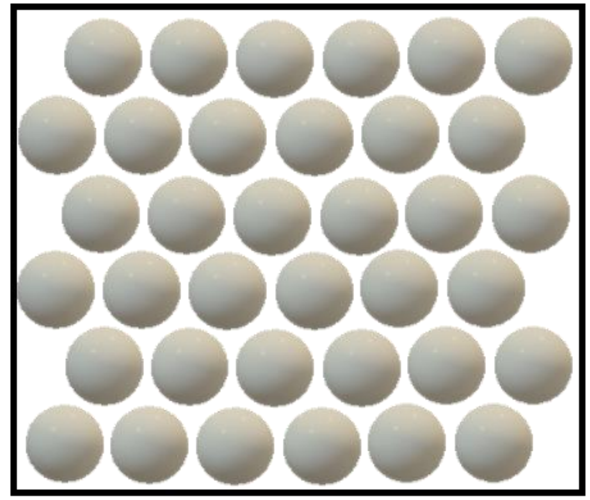
How could nanoparticle structuring occur in confined spaces?

Disorderly close-packed particles



Volume Fraction: 64%
Lower entropy

Orderly rearranged particles

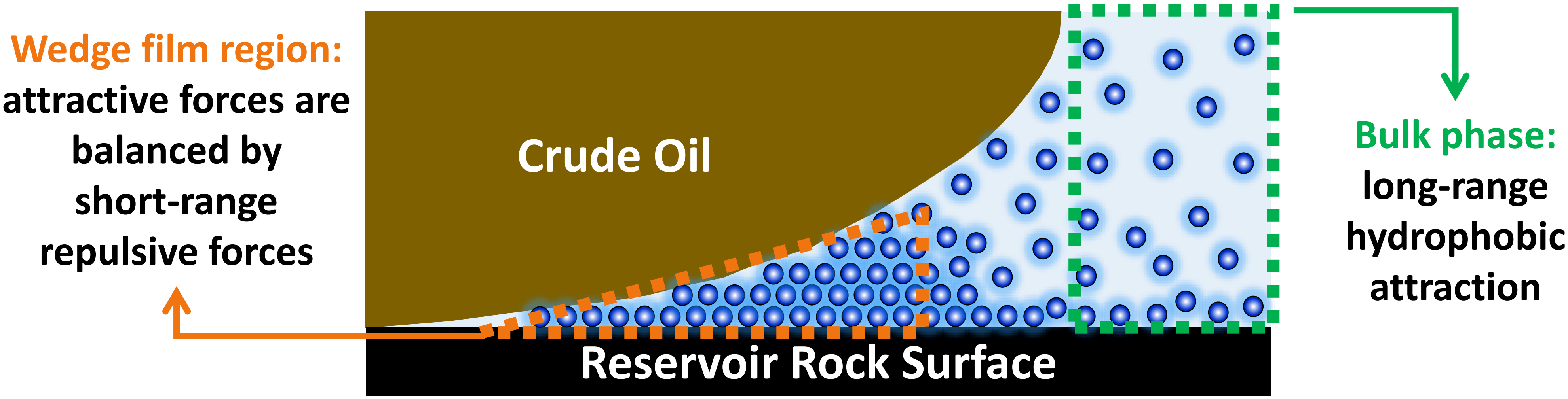


Volume Fraction: 64%
Higher entropy

- Spheres have more freedom to move or vibrate in an ordered structure than in disordered structure in a confined space.
- Ordered nanoparticle structuring is primarily driven by the increase of the entropy
- **Limitations: experimental validation; general design guidelines.**

Manoharan, Vinothan N.*Science* 349.6251 (2015): 1253751.

Properties for nanoparticle structuring in the confined spaces



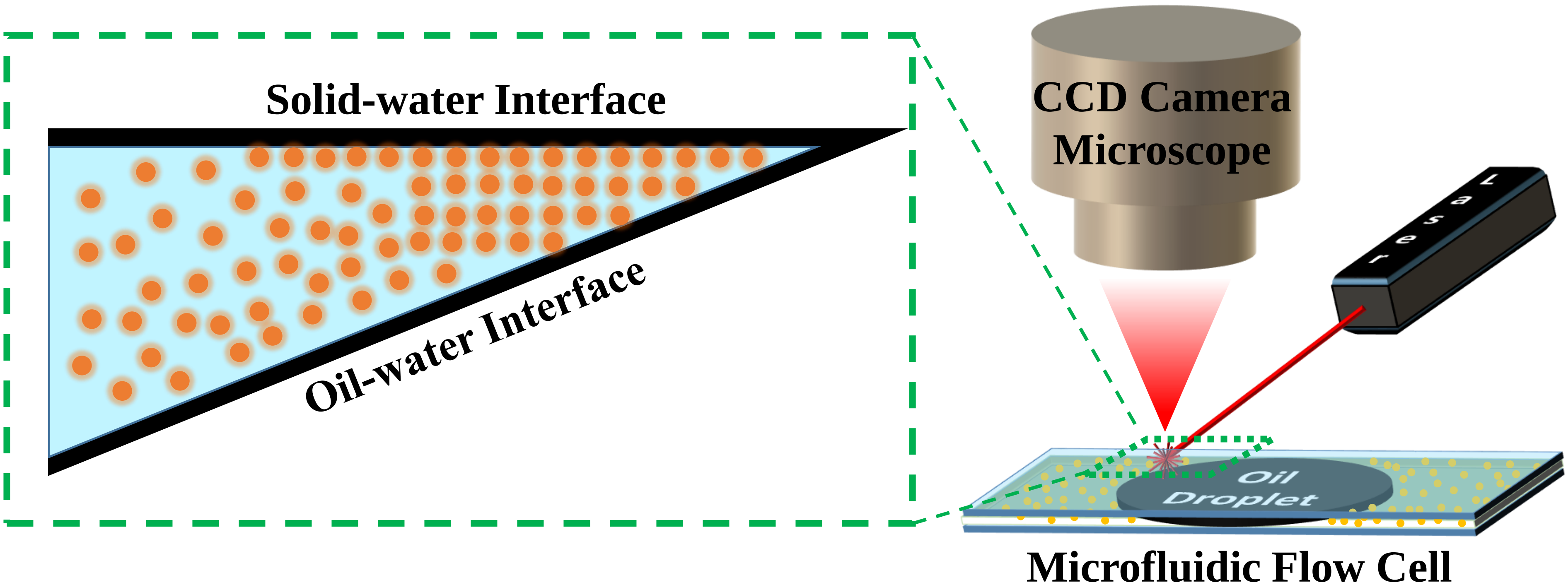
Critical Factors

1. **Brownian Motion (small particle size)**
   - Particle size must be small (<1 µm) to maintain random movement.
2. **Short-range Repulsion (steric, hydration or electrostatic forces)**
   - Required for dispersion of nanoparticle in the bulk.
   - Required for nanoparticle structuring in confined spaces, hence increase the disjoining pressure.
3. **Long-range Attraction (hydrophobic interaction)**
   - Required to draw the nanoparticles into the confined spaces.

How to assess colloidal structure in confined spaces?

Nanoparticle Tracking Analyzer —ZetaView®

- Measure the particle size and size distribution.
  Particle size range: (20 nm –1000 nm) ;
  Reproducibility: (± 2 nm for 100 nm polystyrene latex particle standard)
- Measure the local colloidal concentration and use the probability density distribution function to assess the degree of particle structuring.
  Concentration range: (10^5 - 10^9 particles/ml)



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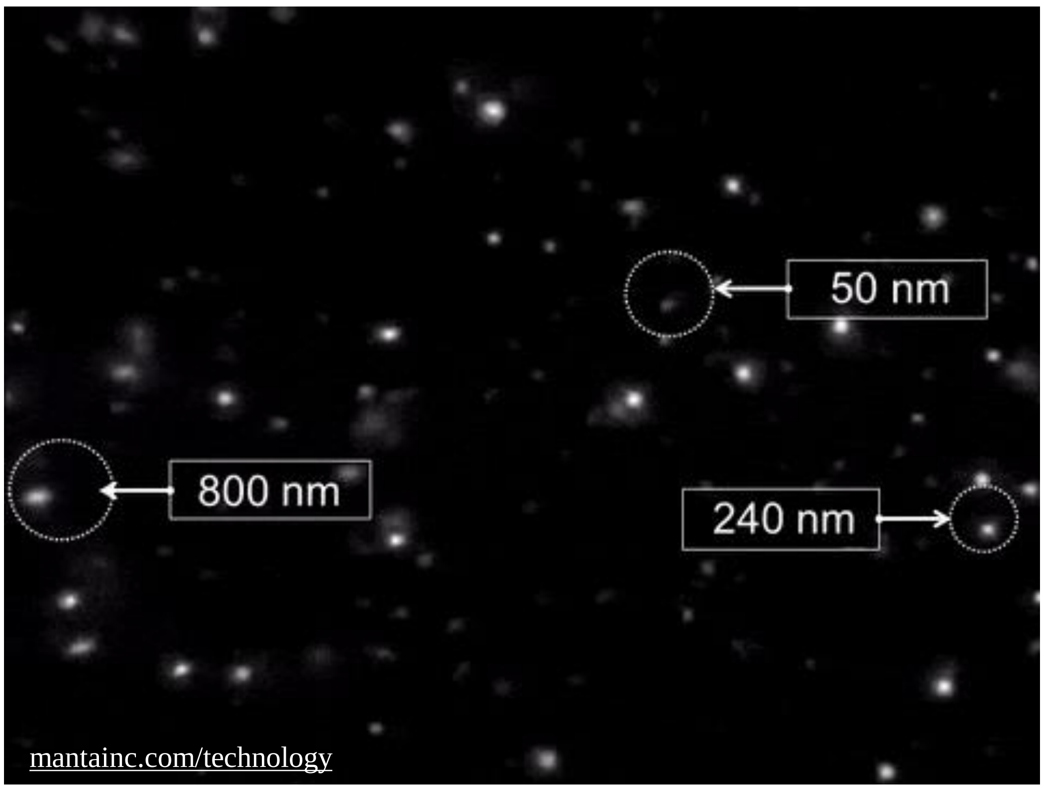
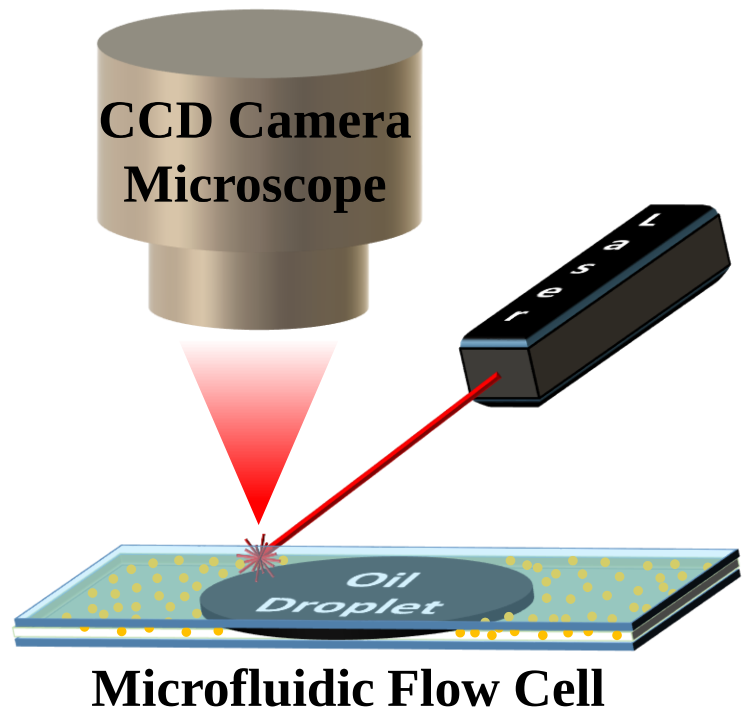
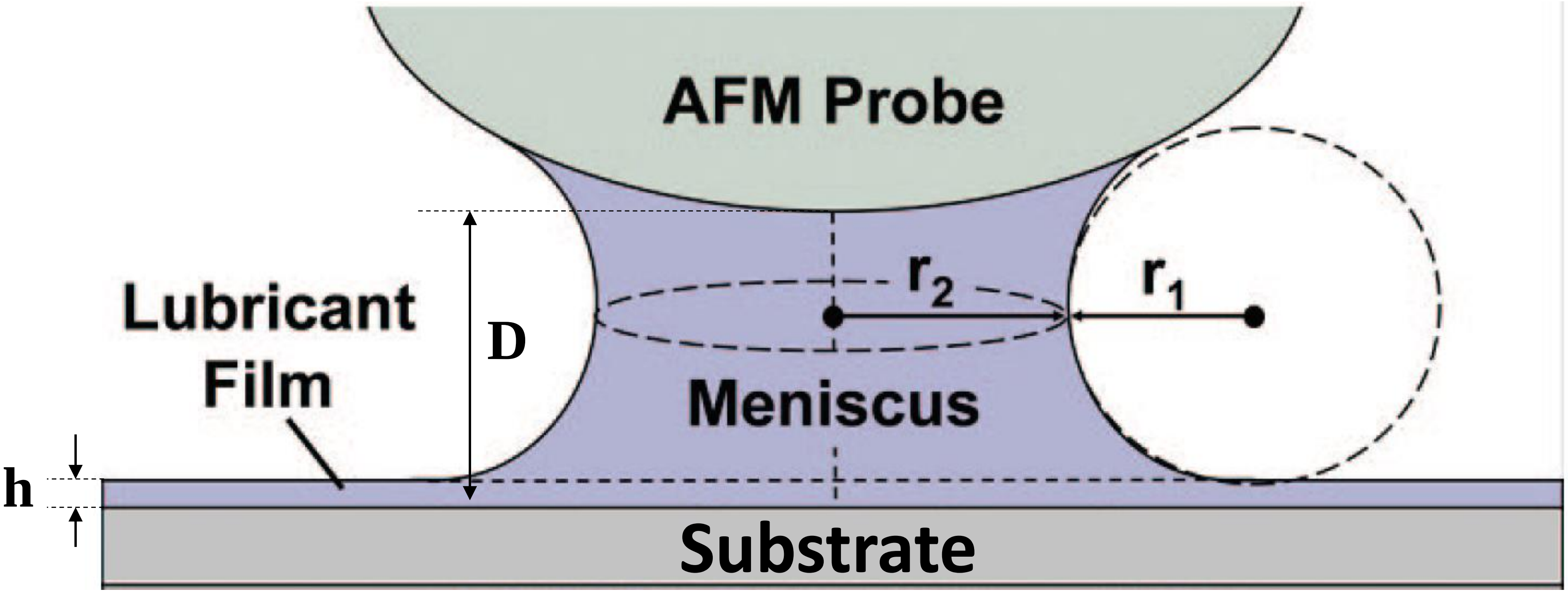




Determination of Disjoining Pressure using AFM



$$\Pi(h) = -\Delta P = \frac{\gamma_{lg}}{r_{eff}}$$

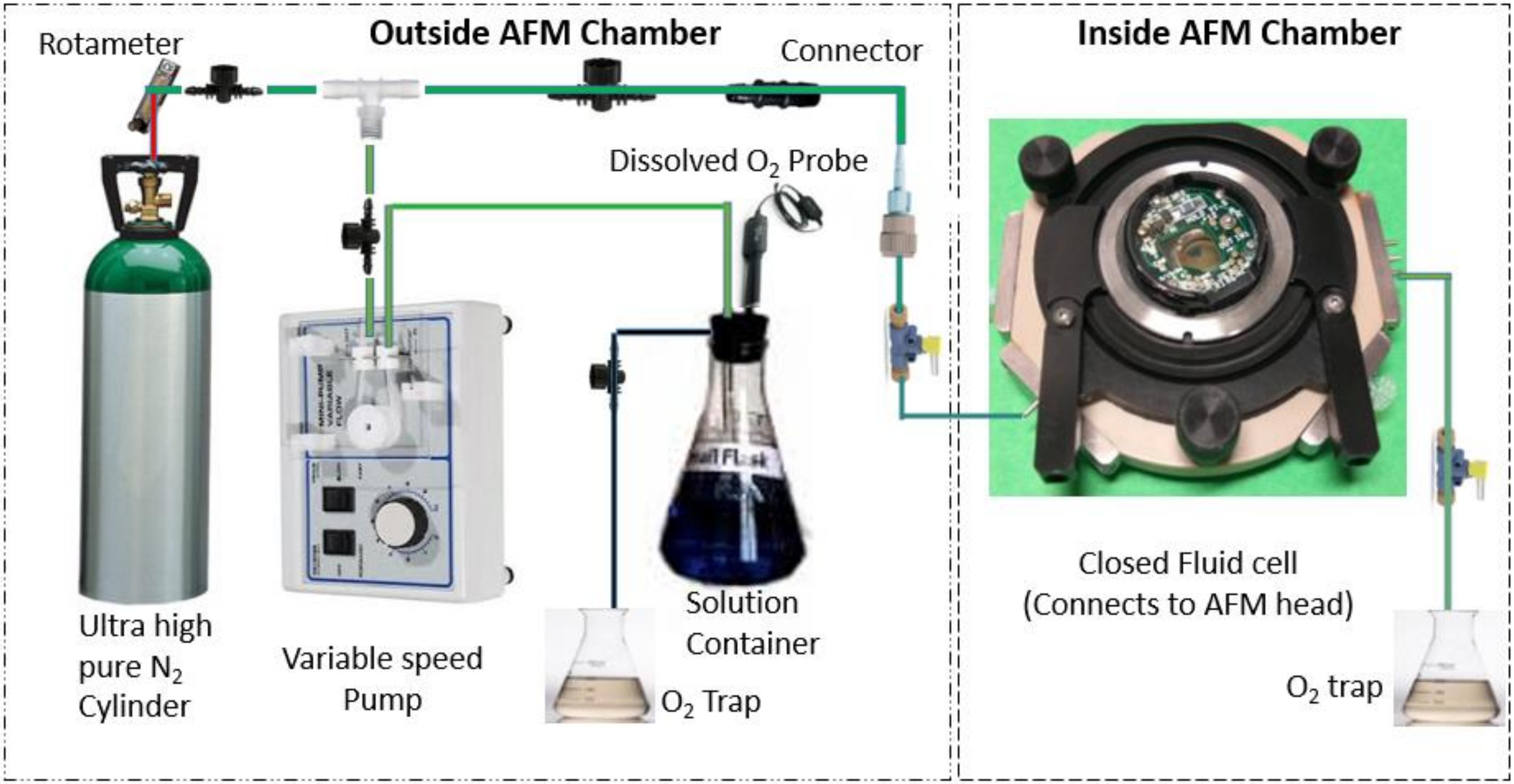
$$\frac{1}{r_{eff}} = -(\frac{1}{r_1} + \frac{1}{r_2})$$

$$\boldsymbol{F(D) = -4\pi\gamma_{lg}R(1 - \frac{D-h}{2r_{eff}})}$$

Π: disjoining pressure
ΔP: Laplace pressure
γ_{lg}: liquid-gas interfacial tension
r_{eff}: effective radius
r_1& r_2 : principle radii of curvature
$F(D)$: AFM tip force measurement
R: radius of curvature of the AFM tip
h: liquid film thickness

Mate, C. Mathew. "Application of disjoining and capillary pressure to liquid lubricant films in magnetic recording." *Journal of Applied Physics* 72.7 (1992): 3084-3090.

AFM with closed-cell chamber



- Previously developed closed-cell AFM can be used directedly to determine the disjoining pressure under specific conditions.

Proposed Research Plan

Objective

Develop particle design guidelines for targeted applications (enhanced oil recovery, lubrication, removal of microbe from surface…)

System Selection

- Latex nanoparticles
- polysilicon nanoparticles
- Others (in consultation with industry sponsors)

Design Parameters

- **Nanoparticle properties:** particle size, size distribution, wettability
- **Nanofluid properties:** solids loading (colloidal concentration), viscosity

Experimental Plan

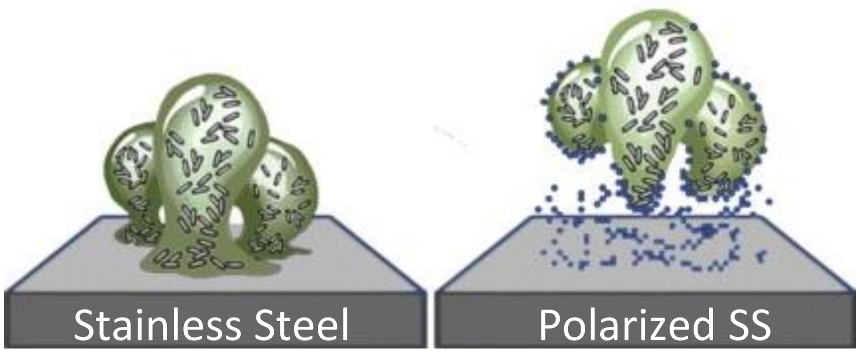
Step 1.
Identify the critical properties required for nanoparticle structuring in confined space. Establish the property-behavior relationship.

Step 2.
Establish the correlation between the nanoparticle structuring and the disjoining pressure.

Step 3.
Evaluate the performance of the designed nanoparticles by testing the oil recovery efficiency.

Applicable for both Hard and Soft Particles (Micelles)

Microbes Removal



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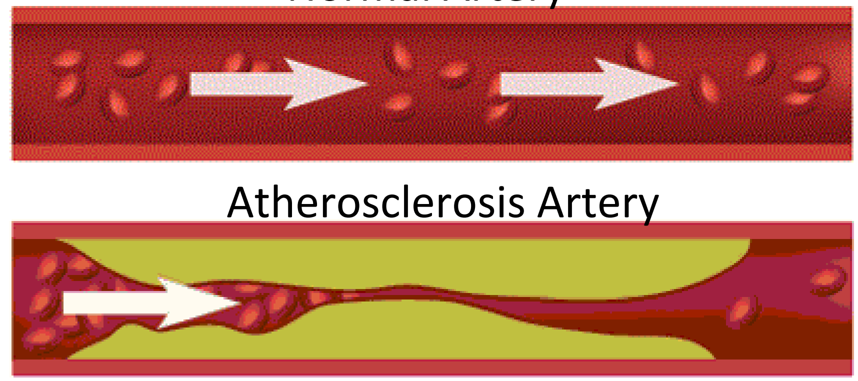
Medical Application



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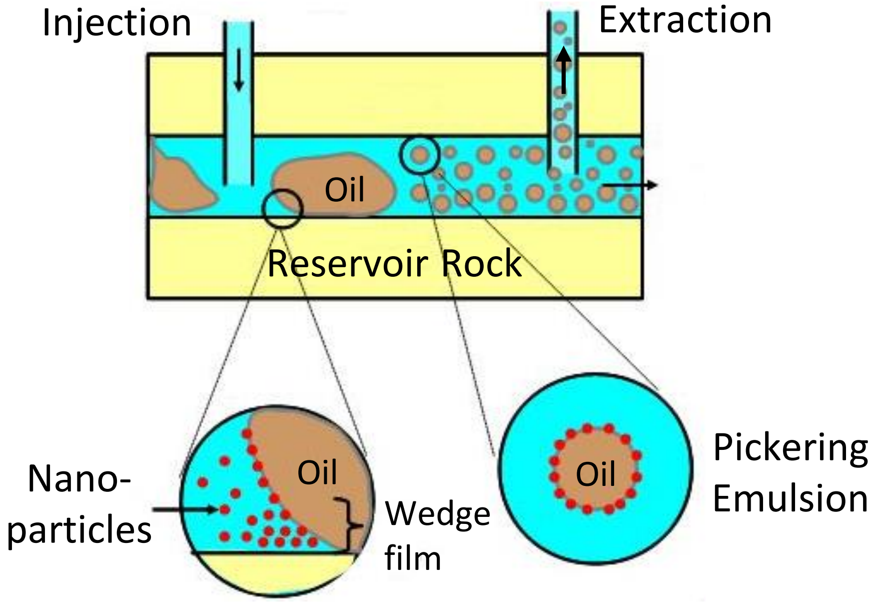
Enhanced Oil Recovery



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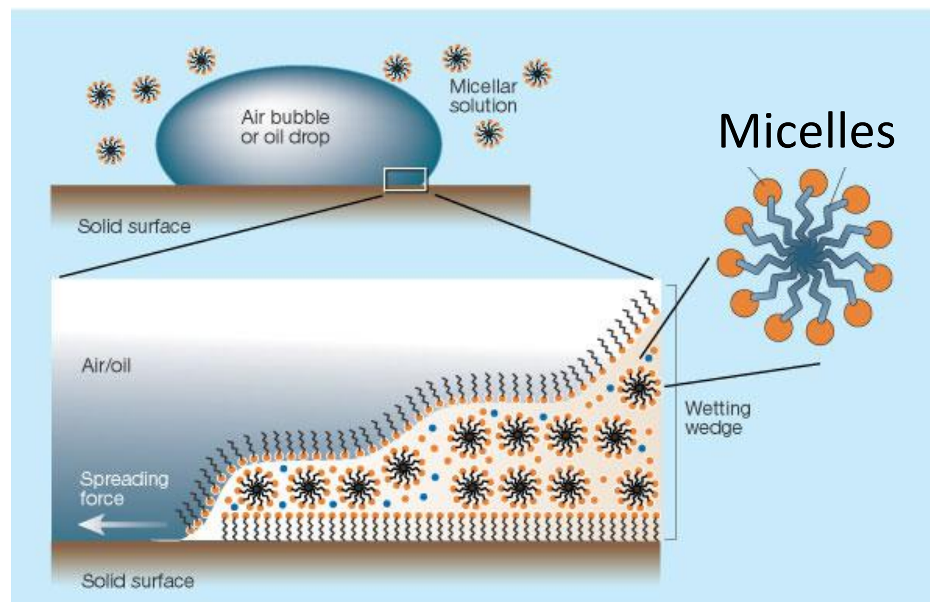

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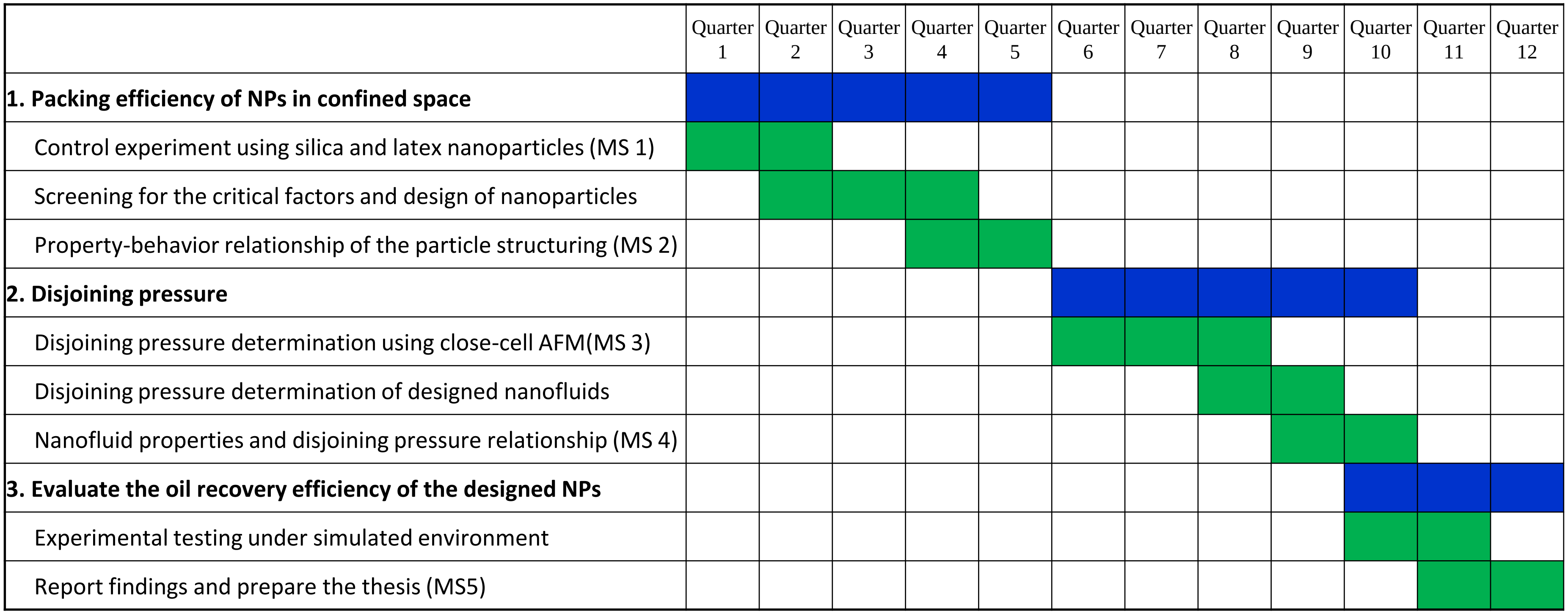
Timeline of Milestones & Deliverables



Milestones:

1. Technique and protocols of characterization of nanoparticle structuring. (Qtr. 2)
2. Determine the critical properties and their roles in nanoparticle structuring. (Qtr. 5)
3. Technique and protocols of measuring disjoining pressures using AFM. (Qtr. 8)
4. Correlations of the nanofluid properties with the disjoining pressure. (Qtr. 10)
5. Property-performance relationship of the designed nanofluid for EOR (Qtr. 12)

Deliverable: design guidelines for nanoparticulate fluid formulation for targeted application.

Budget: $70k per year (duration: three years)

Thank you