MANCHESTER 1824
The University of Manchester

Understanding Highly Concentrated Emulsions

Koay Ze Nian, Claudio Pereira da Fonte, Sergio Carrillo de Hert, and Thomas L. Rodgers

School of Chemical Engineering and Analytical Science
The University of Manchester

MANCHESTER
1824
The University of Manchester

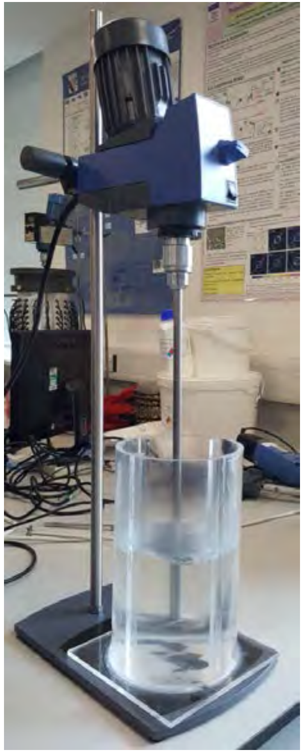
Emulsions

- Properties
  - stability
  - rheology
  - available interfacial area

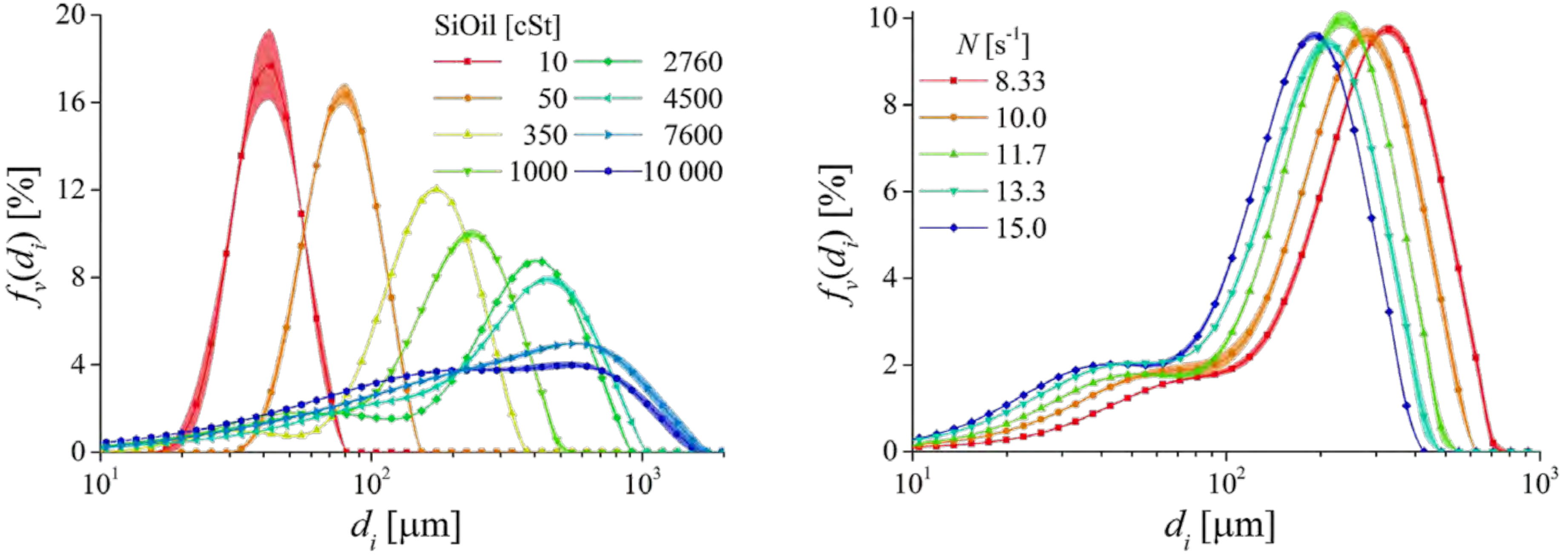
The University of Manchester

Materials and Methods

- 6-PBT 45˚ D ≈ 5 cm
- T = 14 cm, D/C = 3, T/H = 1 and V= 1.97 L
- 1% Volume of oil
- 1% SLES
- Five stirring speeds 500 - 900 rpm
- Oil injected in the vicinity of the impeller
- Emulsification time: 24 h
- Mastersizer 3000, laser diffraction particle size analyser



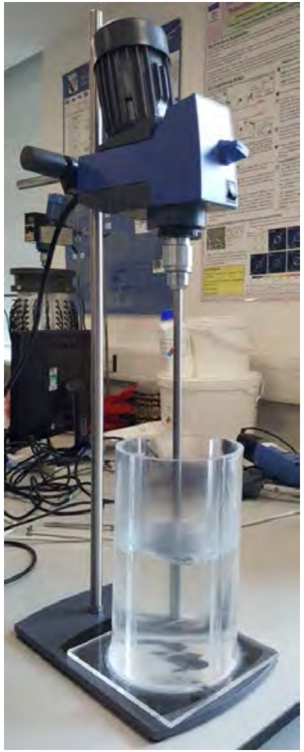
Effect of Oil Viscosity and Agitation



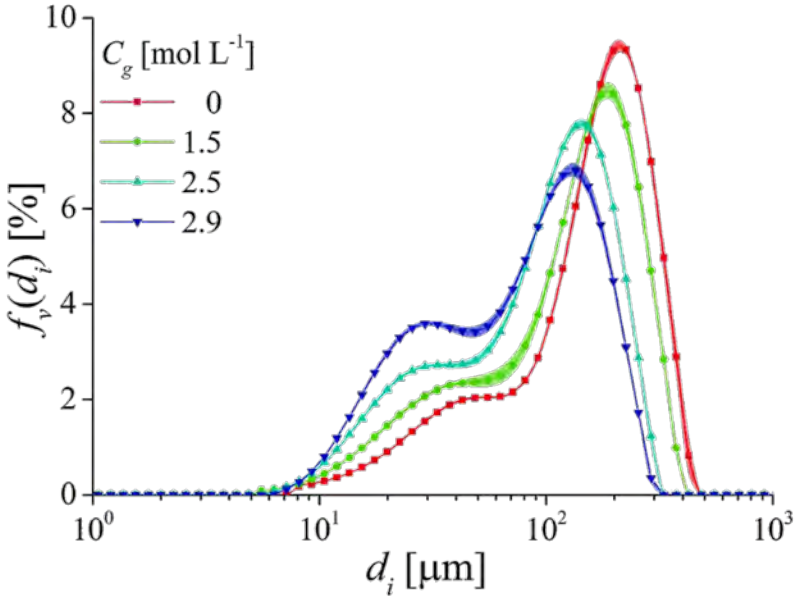
The University of Manchester

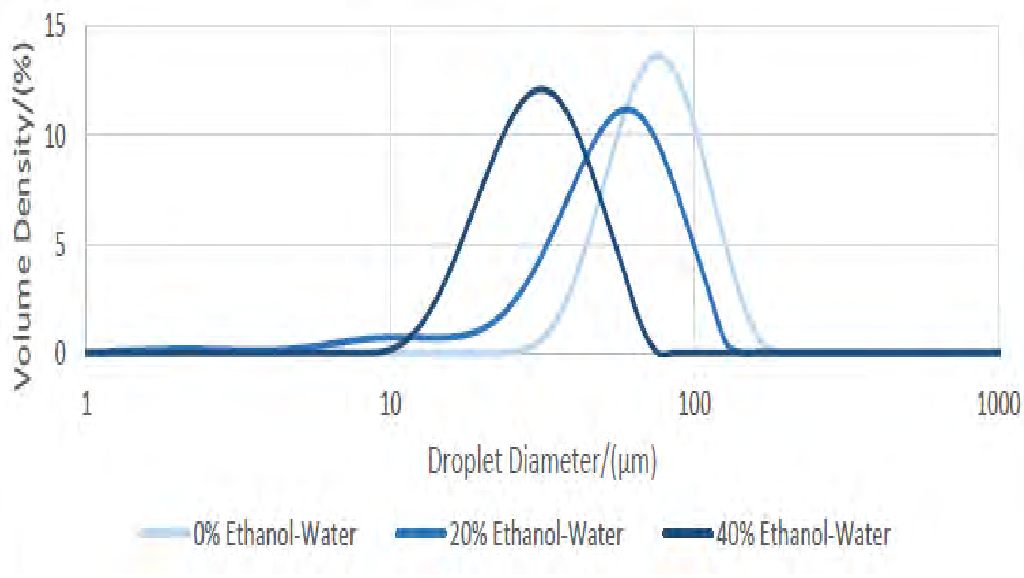
Materials and Methods

- 6-PBT 45˚ D ≈ 5 cm
- T = 14 cm, D/C = 3, T/H = 1 and V= 1.97 L
- 1 – 0.1% Volume of oil
- Glucose syrup in continuous phase
- Ethanol in continuous phase
- 0 – 1% SLES
- Five stirring speeds 500 - 900 rpm
- Oil injected in the vicinity of the impeller
- Emulsification time: 24 h
- Mastersizer 3000, laser diffraction particle size analyser



Effect of Continuous Phase and Interfacial Tension

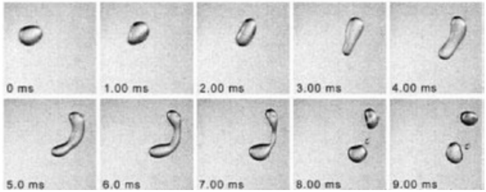


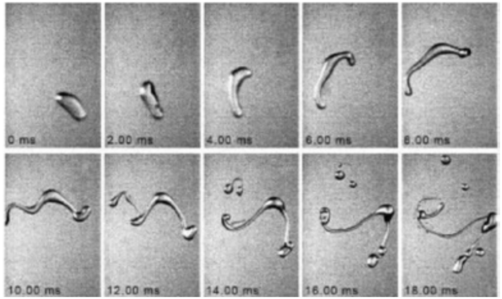


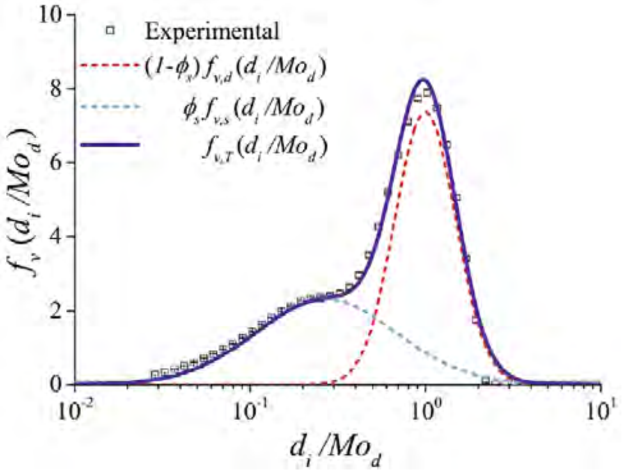
Emulsification – Model

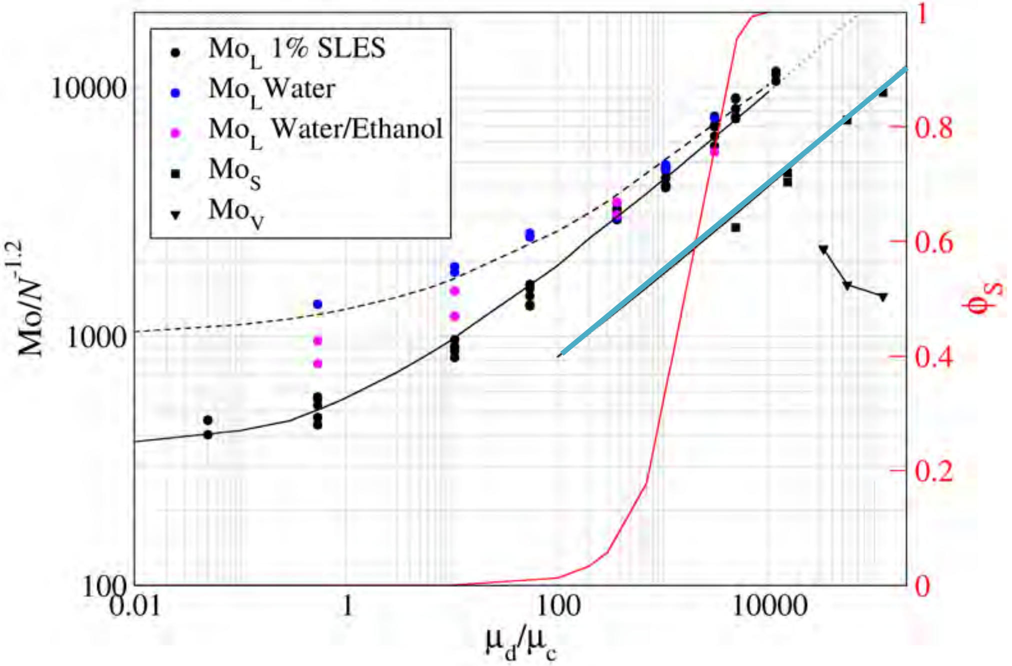
$$f_{v,T}\left(\frac{d_i}{Mo_d}\right)=(1-\phi_s)f_{v,d}\left(\frac{d_i}{Mo_d}\right)+\phi_s f_{v,s}\left(\frac{d_i}{Mo_d}\right)$$

$$Mo_L = A\,N^{-1.2}\sigma^{0.6}\left[1 + B\,\sigma^{-0.6}\left(\frac{\nu_d}{\nu_c}\right)^{0.375}\right]$$







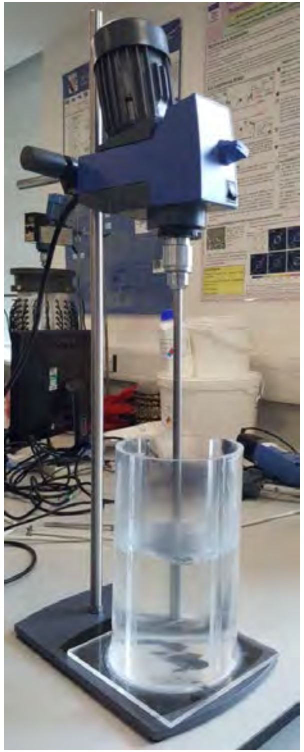


Carrillo De Hert and Rodgers (2018) AIChE J.

MANCHESTER 1824
The University of Manchester

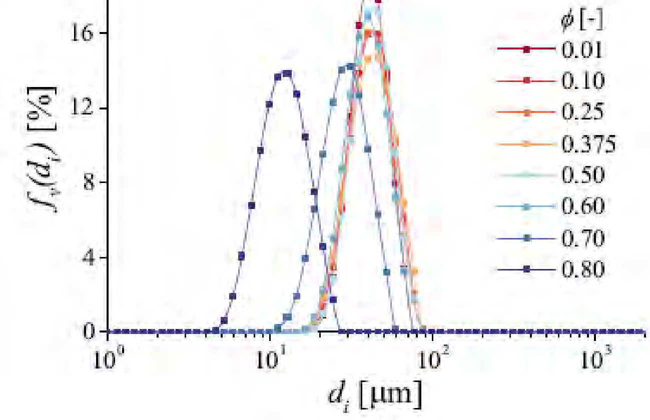
Materials and Methods

- 6-PBT 45˚ D ≈ 5 cm
- T = 14 cm, D/C = 3, T/H = 1 and V= 1.97 L
- 0.1 – 80 % Volume of oil
- 1% SLES
- Five stirring speeds 500 - 900 rpm
- Oil injected in the vicinity of the impeller
- Emulsification time: 24 h
- Mastersizer 3000, laser diffraction particle size analyser

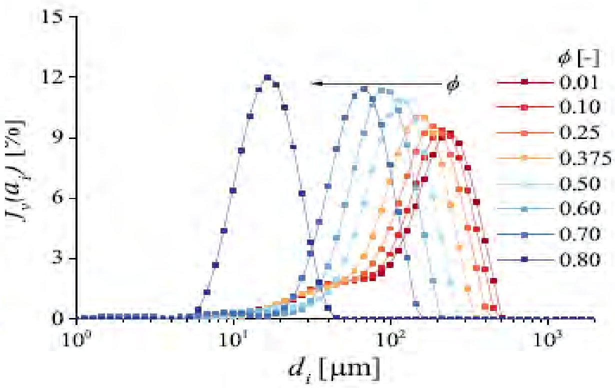


Effect of Volume Fraction

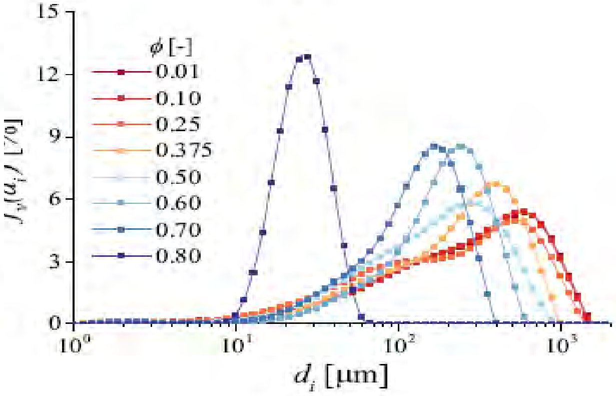
10 cSt



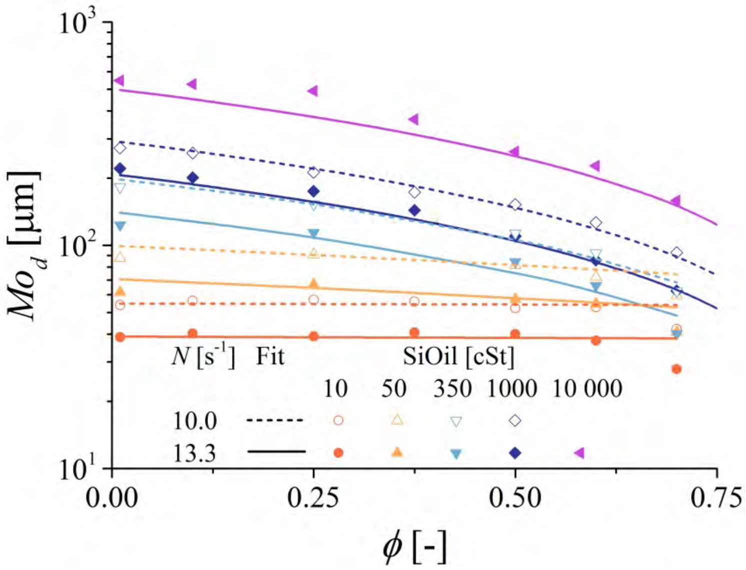
1,000 cSt

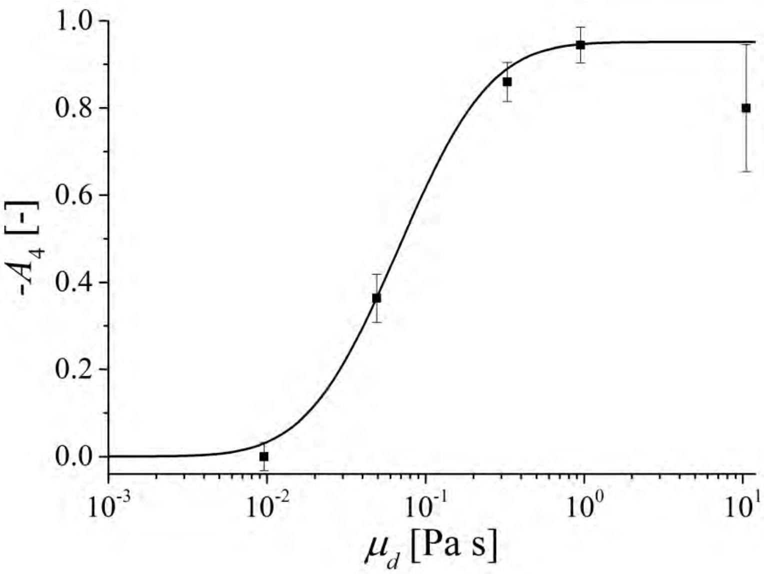


10,000 cSt



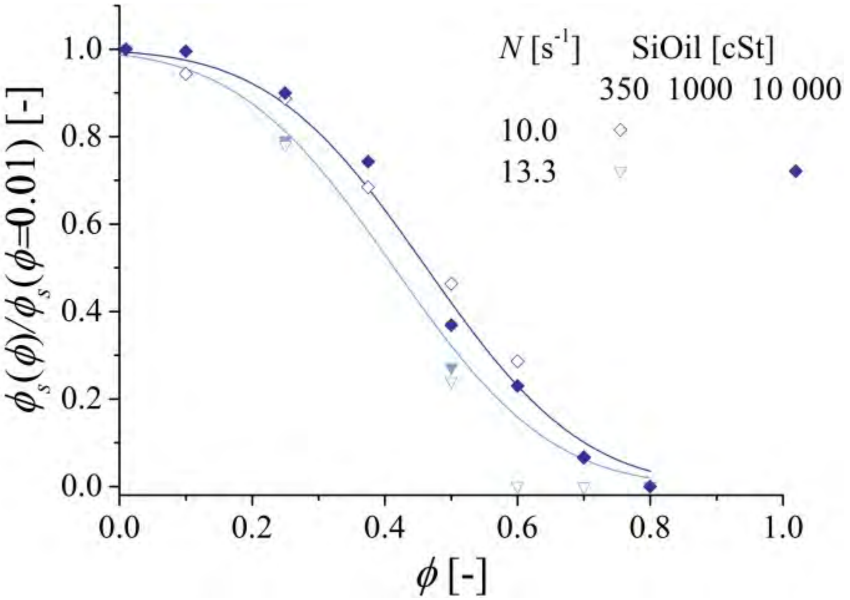
Effect of Volume Fraction

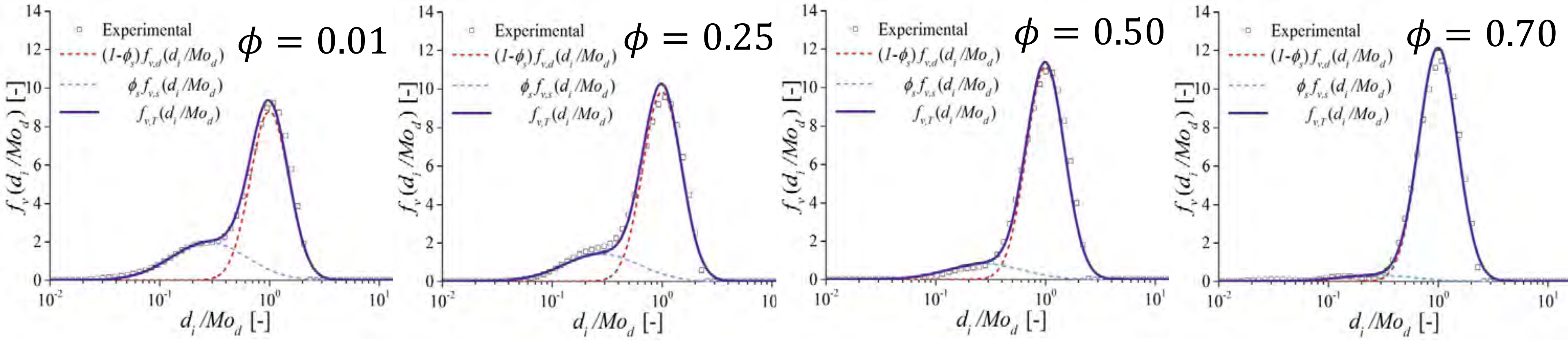




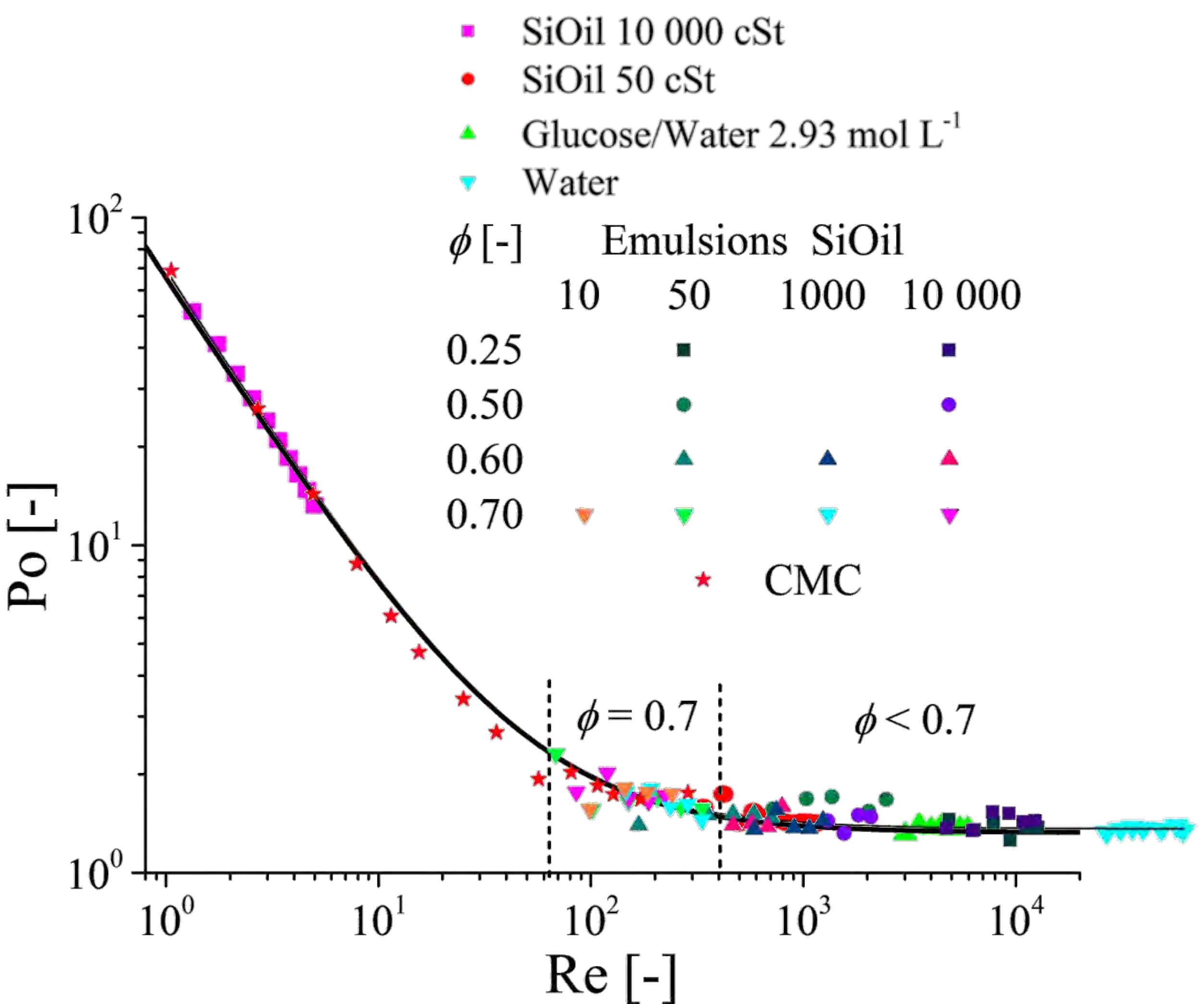
$$Mo_L = A\,N^{-1.2}\sigma^{0.6}\left[1 + B\,\sigma^{-0.6}\left(\frac{\nu_d}{\nu_c}\right)^{0.375}\right](1 + A_4\phi)$$

Effect of Volume Fraction





Rheology

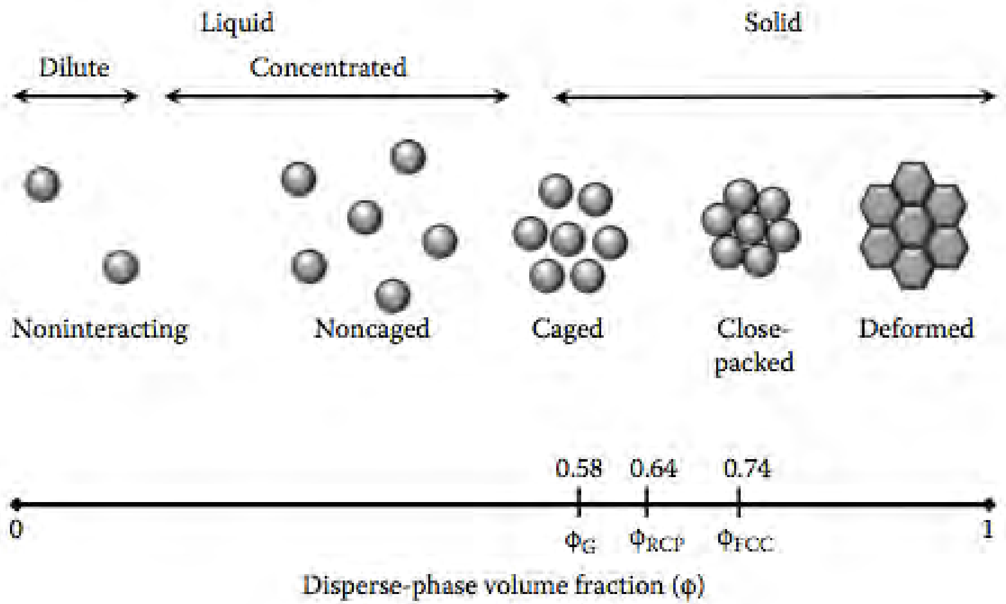

SiOil 10 000 cSt
SiOil 50 cSt
Glucose/Water 2.93 mol L-1
Water
ϕ [-]
Emulsions SiOil
10
50
1000
10 000
0.25
0.50
0.60
0.70
CMC
ϕ = 0.7
ϕ < 0.7
Po [-]
Re [-]
10^0
10^1
10^2
10^3
10^4

The University of Manchester

Rheology

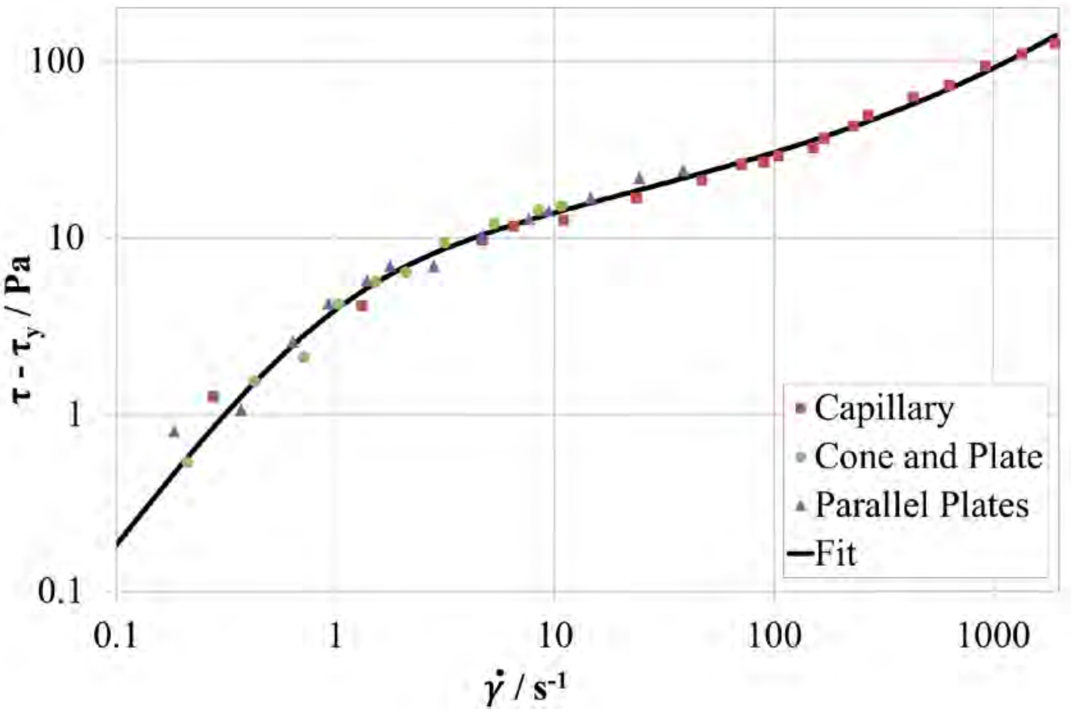
- Complex
  - Yield Stress
  - Droplets moving
  - Aligned movement
  - Continuous phase/surfactant

$$\eta = \begin{cases} \mu_0 & \dot{\gamma} \le \dot{\gamma}_y \\ \tau_y \dot{\gamma}^{-1} + \mu_\infty + \dfrac{k_1 \dot{\gamma}^{n_1} - \mu_\infty}{1 + k_2 \dot{\gamma}^{n_2}} & \dot{\gamma} > \dot{\gamma}_y \end{cases}$$



Rheology – Dense phase Slurry

$$\eta = \begin{cases} \mu_0 \\ \tau_y \dot{\gamma}^{-1} + \mu_\infty + \dfrac{k_1 \dot{\gamma}^{n_1} - \mu_\infty}{1 + k_2 \dot{\gamma}^{n_2}} \end{cases}$$



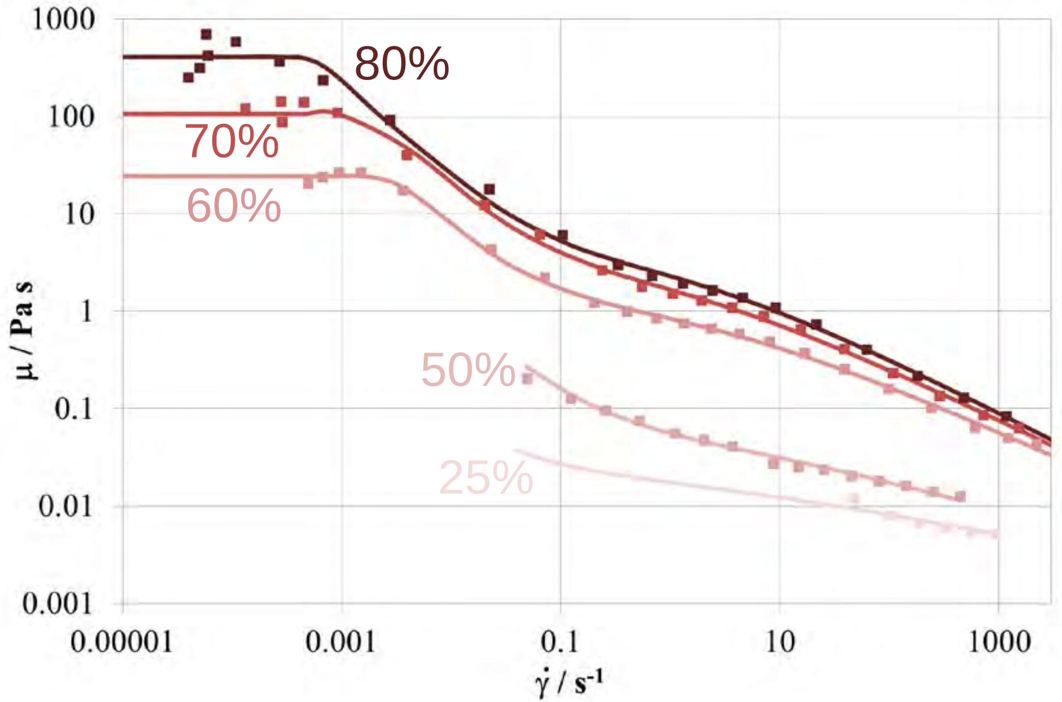
Data from Dervisoglu and Kokini (1986) J. Food Sci.

Volume Fraction Effect – Rheology

$$\eta = \begin{cases} \mu_0 & \dot{\gamma} \leq \dot{\gamma}_y \\ \tau_y \dot{\gamma}^{-1} + \cancelto{0}{\mu_\infty} + \dfrac{k_1 \dot{\gamma}^{n_1} - \cancelto{0}{\mu_\infty}}{1 + k_2 \dot{\gamma}^{n_2}} & \dot{\gamma} > \dot{\gamma}_y \end{cases}$$

50 cSt oil —

Water —



MANCHESTER 1824
The University of Manchester

Conclusions

- Low concentration emulsions follow expected theory
- High concentrations produce emulsions that are:
    - Smaller
    - More mono-modal
- Rheology is controlled by drop size and phase fraction