CUNY ENERGY INSTITUTE

PIRE Thrust IV: Phase-Change-Material Nanoemulsions for Energy Transport and Storage

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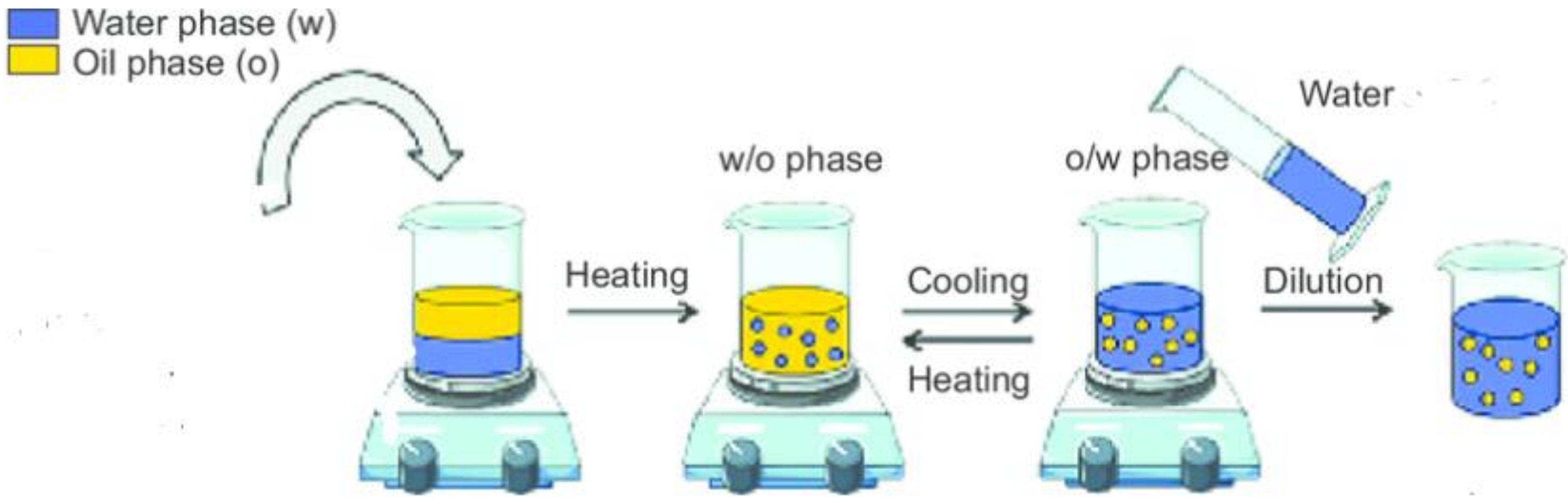
the City College of New York

Preparation of Emulsion

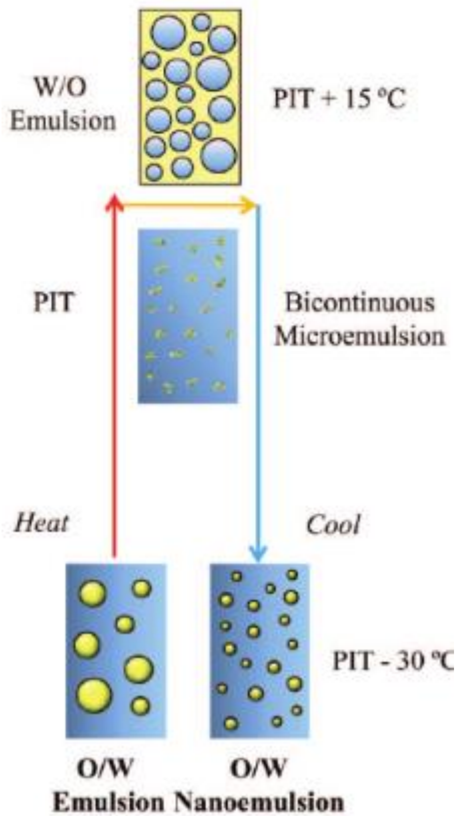
	Solution 1	Solution 2	Solution 3	Solution 4
Octadecane mass (g)	120	120	120	120
Water mass (g)	340	320	320	300
Span 60 mass (g)	4	7	10	13.5
Tween 60 mass (g)	10.4	18.2	26	35.1
Volume Fraction of Oil	0.303158528	0.308968639	0.302623657	0.307341038
Weight Percentage of Oil	25.29510961	25.79535684	25.21008403	25.60819462
Weight Percentage of Water	71.66947723	68.78761823	67.22689076	64.02048656
Weight Percentage of Span 60	0.84317032	1.504729149	2.100840336	2.880921895
Weight Percentage of Tween 60	2.192242833	3.912295787	5.462184874	7.490396927
Weight Percentage of Surfactants	3.035413153	5.417024936	7.56302521	10.37131882
Volume of Water (mL)	341.0230692	320.9628887	320.9628887	300.9027081
Volume of Octadecane (mL)	154.4401544	154.4401544	154.4401544	154.4401544
Total Volume (mL)	509.4369456	499.8570565	510.3373479	502.5041741
Surfactant/Oil Mass Ratio	0.12	0.21	0.3	0.405
Surfactant/Oil Volume Ratio	0.09047985	0.158339737	0.226199624	0.305369492
Oil/Surfactant Mass Ratio	8.333333333	4.761904762	3.333333333	2.469135802

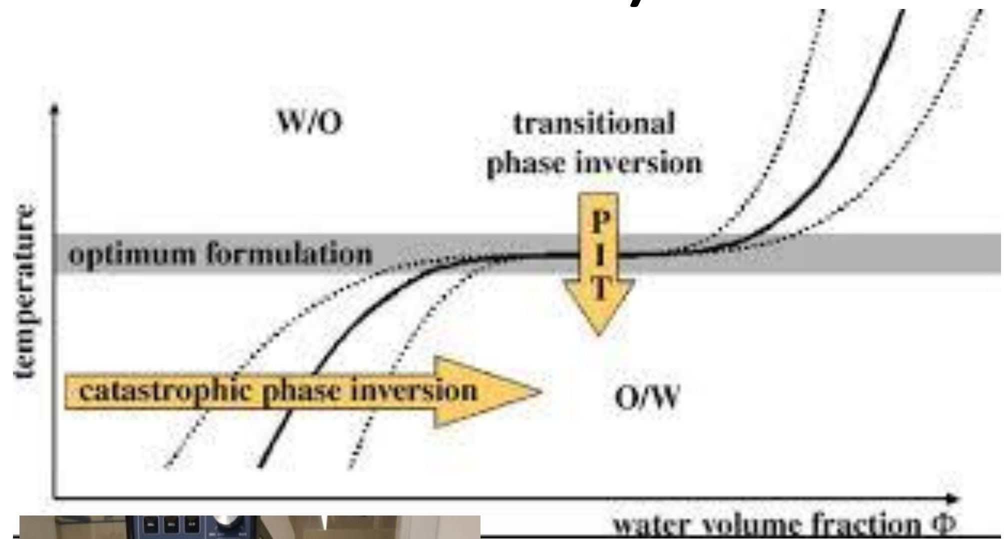
	Vol. Fraction	**Vol. of Test Tube (mL)**	Vol. of Oil (mL)	Surfactant/Oil Mass Ratio	Surfactant/Oil Volume Ratio	Vol. of Surfactants	Vol. of Water	**Added Vol. of Water**	New Vol. of Water	**New Vol. Fraction**	New Total Volume
Solution 1	0.303158528	50	15.15792639	0.12	0.09047985	1.371486899	33.47058671	0	33.47058671	0.303158528	50
	0.303158528	33	10.00423142	0.12	0.09047985	0.905181353	22.09058723	15	37.09058723	0.208421488	48
	0.303158528	25	7.578963196	0.12	0.09047985	0.685743449	16.73529336	25	41.73529336	0.151579264	50
	0.303158528	15	4.547377917	0.12	0.09047985	0.41144607	10.04117601	30	40.04117601	0.101052843	45
	0.303158528	8	2.425268223	0.12	0.09047985	0.219437904	5.355293874	40	45.35529387	0.050526421	48
	TOTAL Vol X2	262									
Solution 2	0.308968639	50	15.44843195	0.21	0.158339737	2.446100647	32.1054674	0	31.8826441	0.310351711	
	0.308968639	30	9.26905917	0.21	0.158339737	1.467660388	19.26328044	15	34.26328044	0.205979093	45
	0.308968639	24	7.415247336	0.21	0.158339737	1.17412831	15.41062435	25	40.41062435	0.151331578	49
	0.308968639	15	4.634529585	0.21	0.158339737	0.733830194	9.631640221	30	39.63164022	0.102989546	45
	0.308968639	8	2.471749112	0.21	0.158339737	0.391376103	5.136874785	40	45.13687478	0.051494773	48
	TOTAL Vol X2	254									
Solution 3	0.302623657	50	15.13118284	0.3	0.226199624	3.422667866	31.44614929	0	31.44614929	0.302623657	50
	0.302623657	33	9.986580675	0.3	0.226199624	2.258960791	20.75445853	16	36.75445853	0.203807769	49
	0.302623657	25	7.56559142	0.3	0.226199624	1.711333933	15.72307465	25	40.72307465	0.151311828	50
	0.302623657	15	4.539354852	0.3	0.226199624	1.02680036	9.433844788	30	39.43384479	0.100874552	45
	0.302623657	8	2.420989254	0.3	0.226199624	0.547626859	5.031383887	40	45.03138389	0.050437276	48
	TOTAL Vol X2	262									
Solution 4	0.307341038	50	15.3670519	0.405	0.305369492	4.692628833	29.94031927	0	29.94031927	0.307341038	50
	0.307341038	30	9.220231139	0.405	0.305369492	2.8155773	17.96419156	15	32.96419156	0.204894025	45
	0.307341038	24	7.376184911	0.405	0.305369492	2.25246184	14.37135325	25	39.37135325	0.150534386	49
	0.307341038	15	4.610115569	0.405	0.305369492	1.40778865	8.982095781	30	38.98209578	0.102447013	45
	0.307341038	8	2.458728304	0.405	0.305369492	0.750820613	4.790451083	40	44.79045108	0.051223506	48
	TOTAL Vol X2	254									

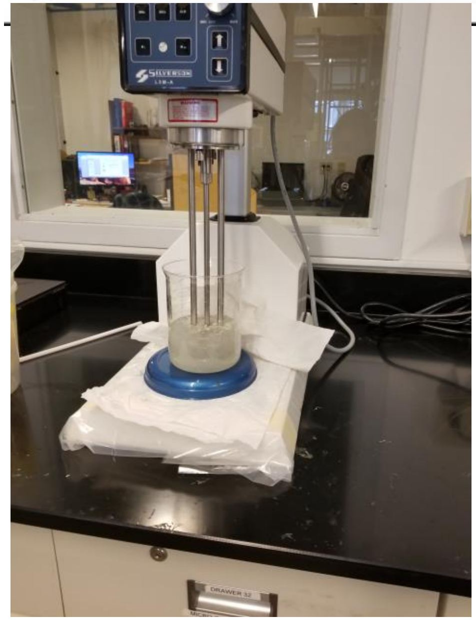
Preparation of Emulsion

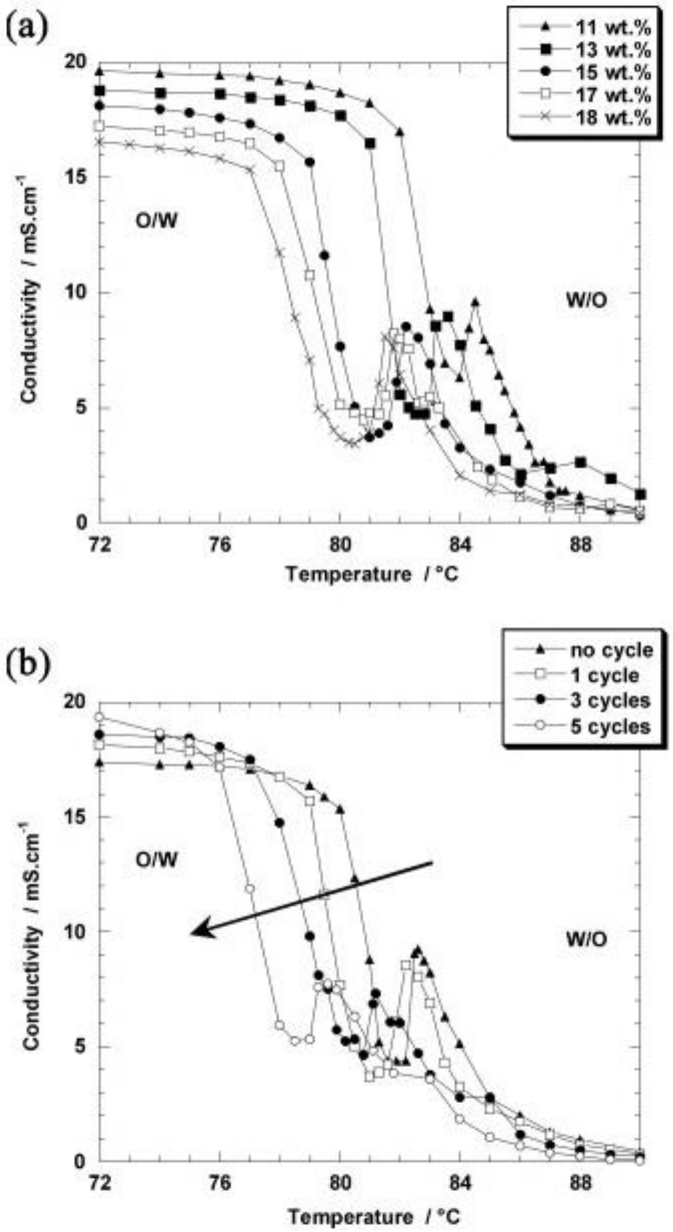


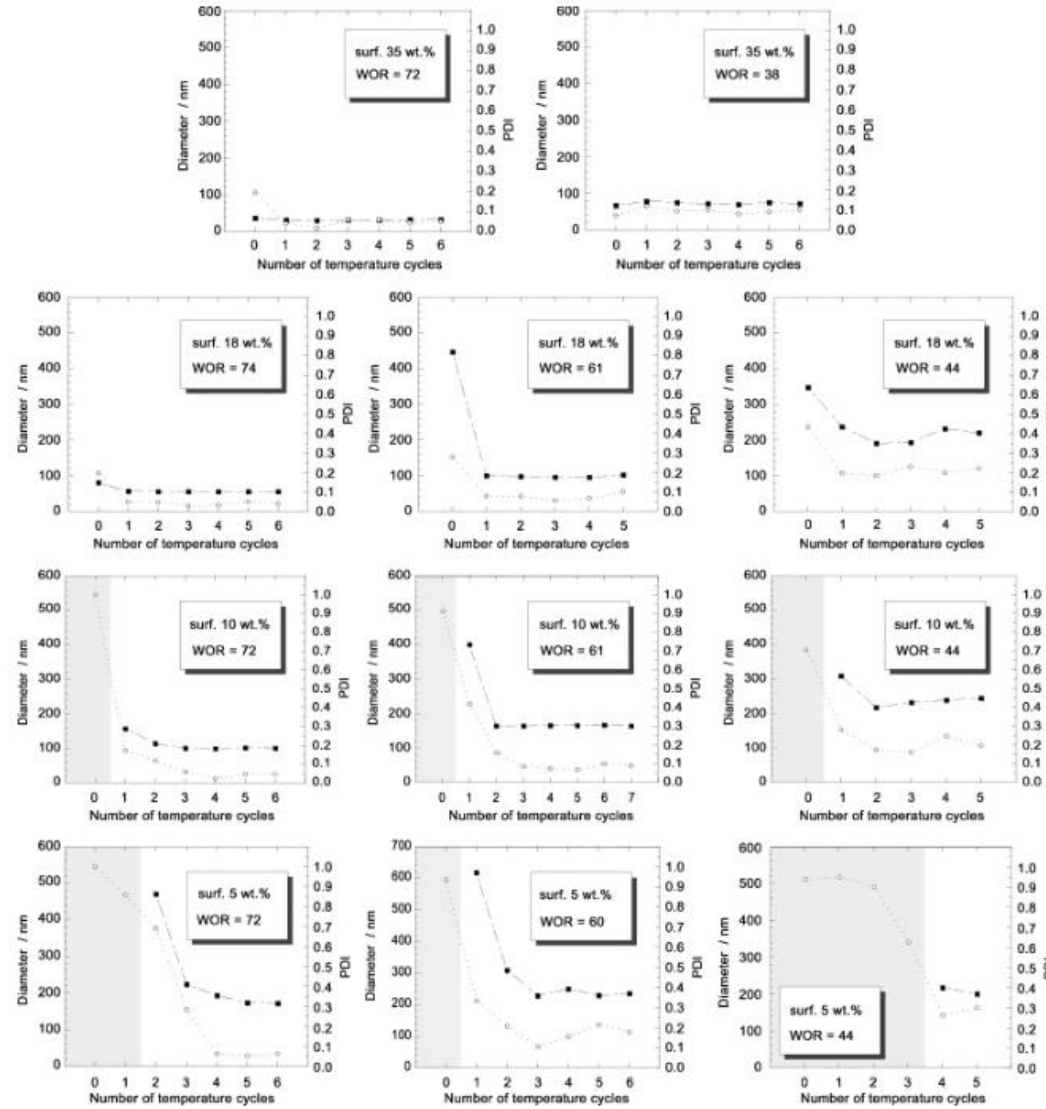
Preparation of Emulsion (Phase Inversion Method)







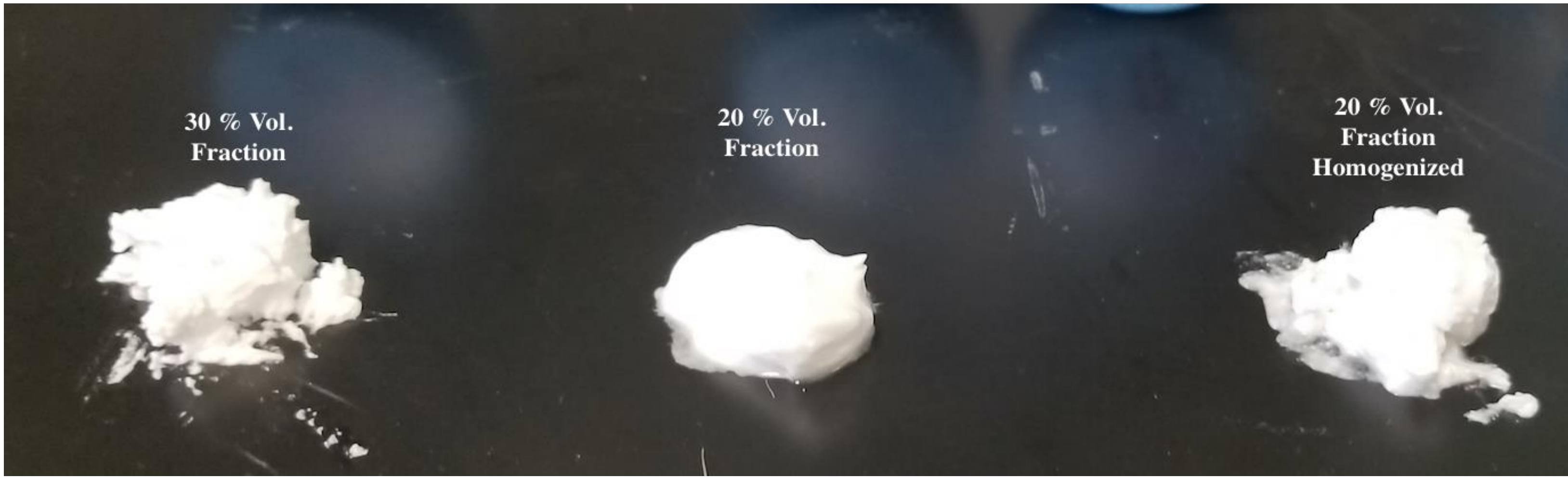

(a)
11 wt.%
13 wt.%
15 wt.%
17 wt.%
18 wt.%
O/W
W/O
Conductivity / mS.cm-1
Temperature / °C
(b)
no cycle
1 cycle
3 cycles
5 cycles
O/W
W/O
Conductivity / mS.cm-1
Temperature / °C


surf. 35 wt.%
WOR = 72
surf. 35 wt.%
WOR = 38
surf. 18 wt.%
WOR = 74
surf. 18 wt.%
WOR = 61
surf. 18 wt.%
WOR = 44
surf. 10 wt.%
WOR = 72
surf. 10 wt.%
WOR = 61
surf. 10 wt.%
WOR = 44
surf. 5 wt.%
WOR = 72
surf. 5 wt.%
WOR = 60
surf. 5 wt.%
WOR = 44
Diameter / nm
PDI
Number of temperature cycles

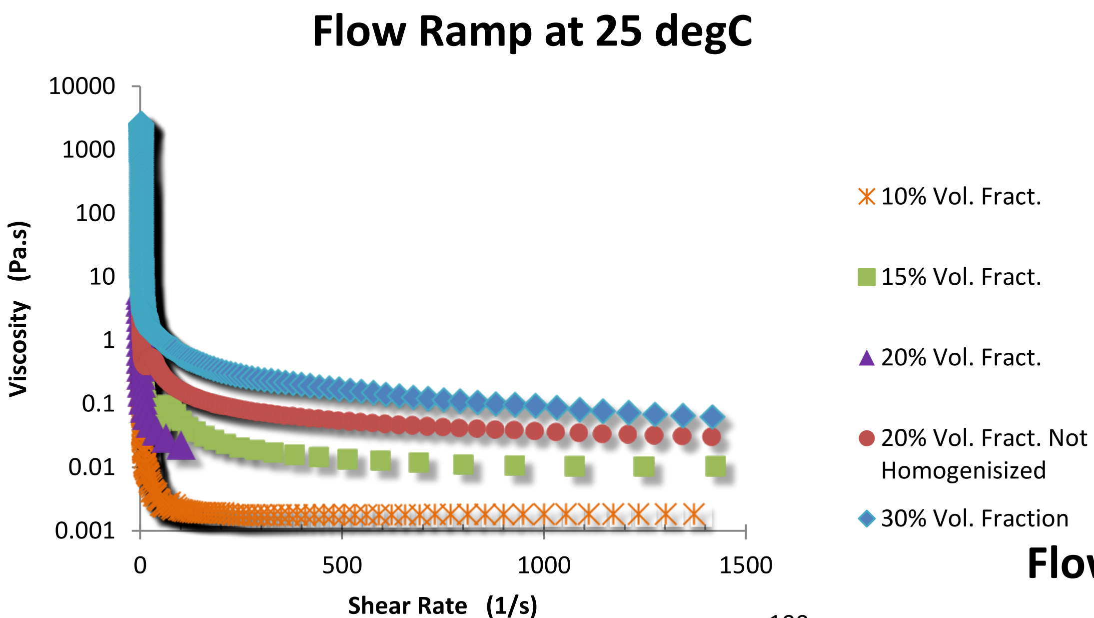
[9]Anton et al

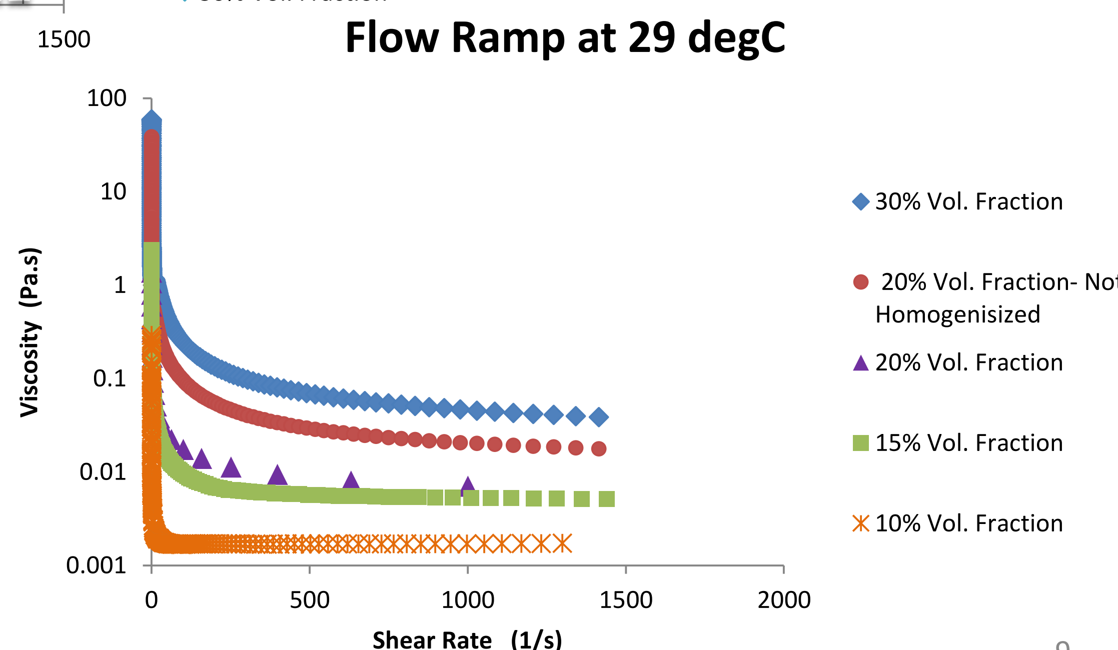
Unstable Emulsions

Solutions containing ~7.5% Weight of Surfactants at 23 degC



Rheological Properties

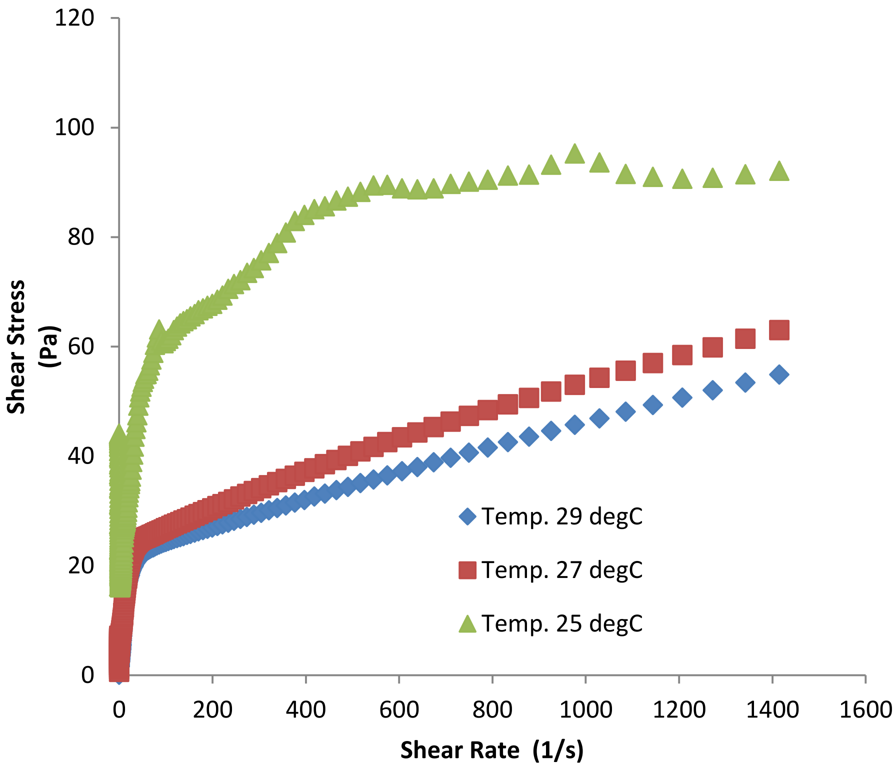


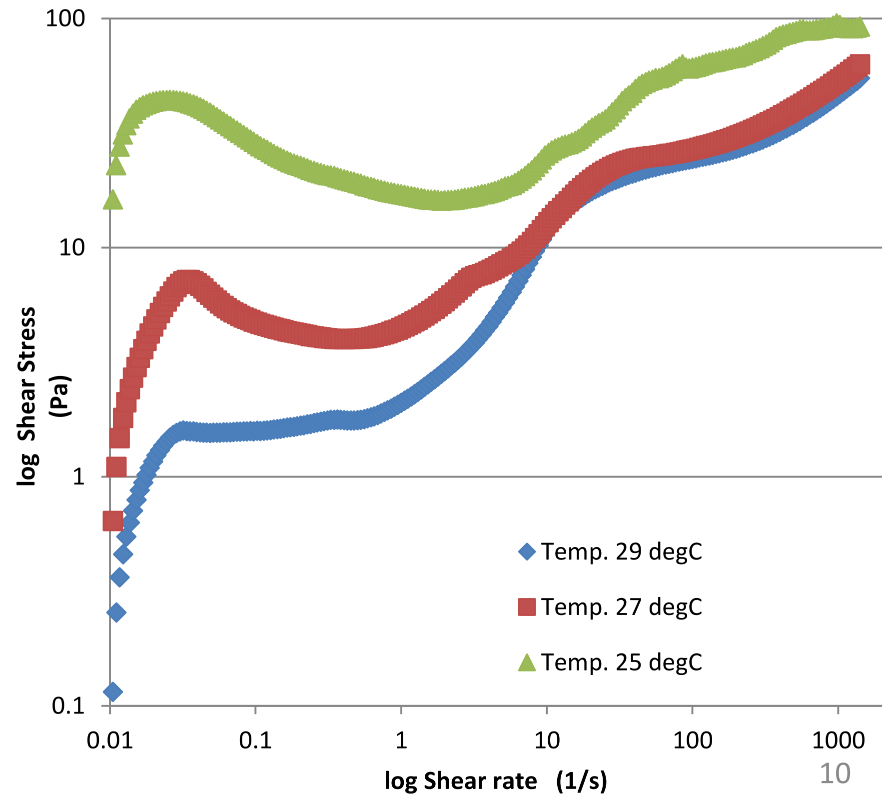


30% and 20% Vol. Fraction were performed with a 50mm Parallel Plate of a gap width of 0.85mm

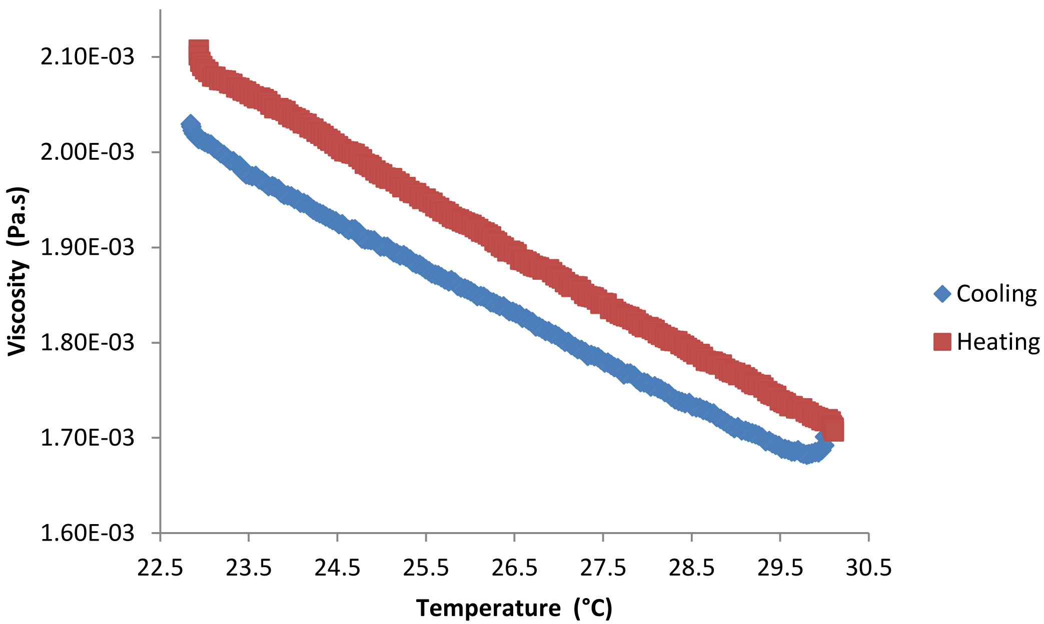
20% and lower vol. fraction performed with coutte cup

30% Vol. Fraction

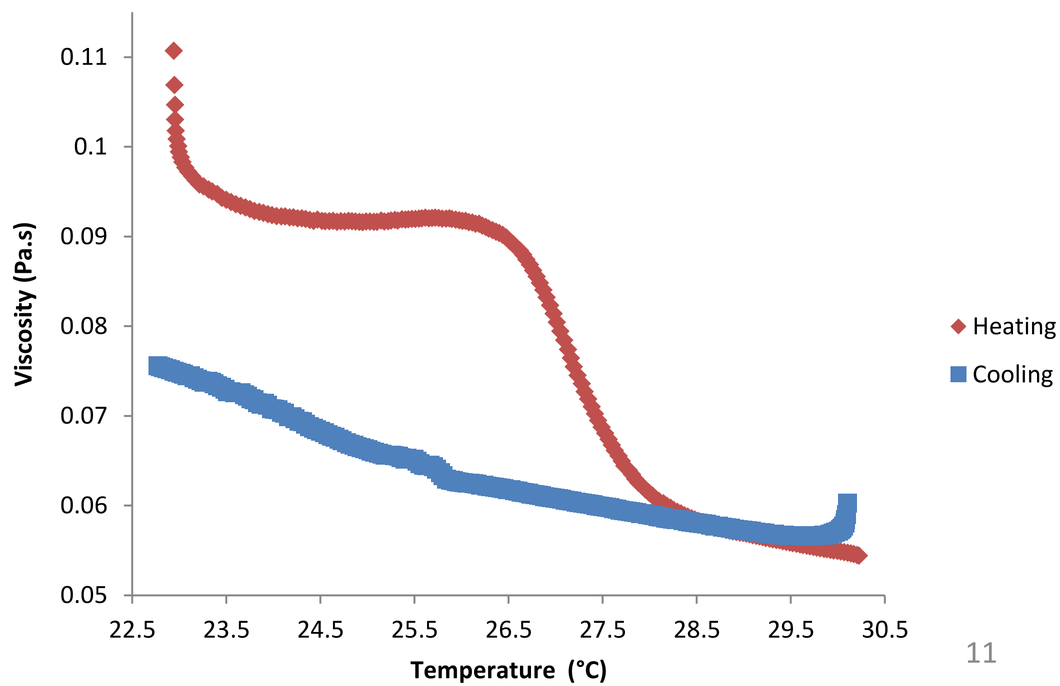




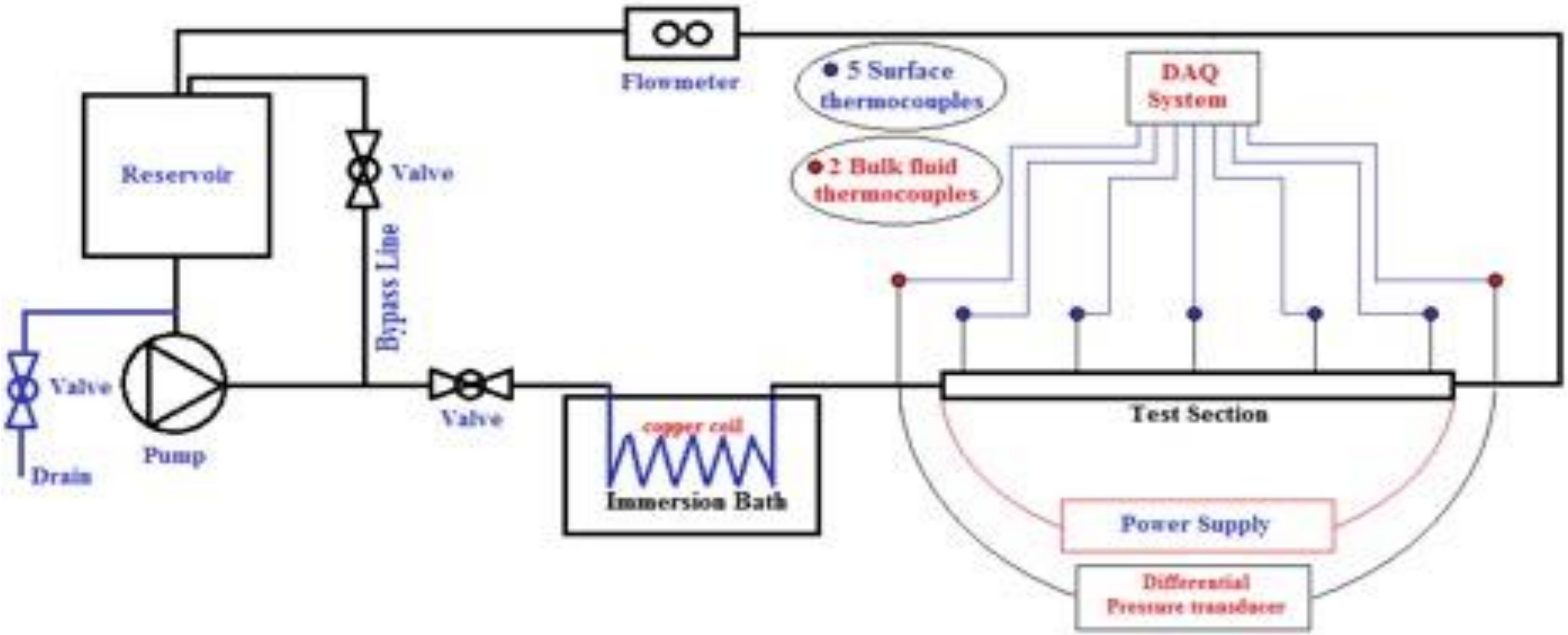
10% Volume Fraction



30 % Vol. Fraction

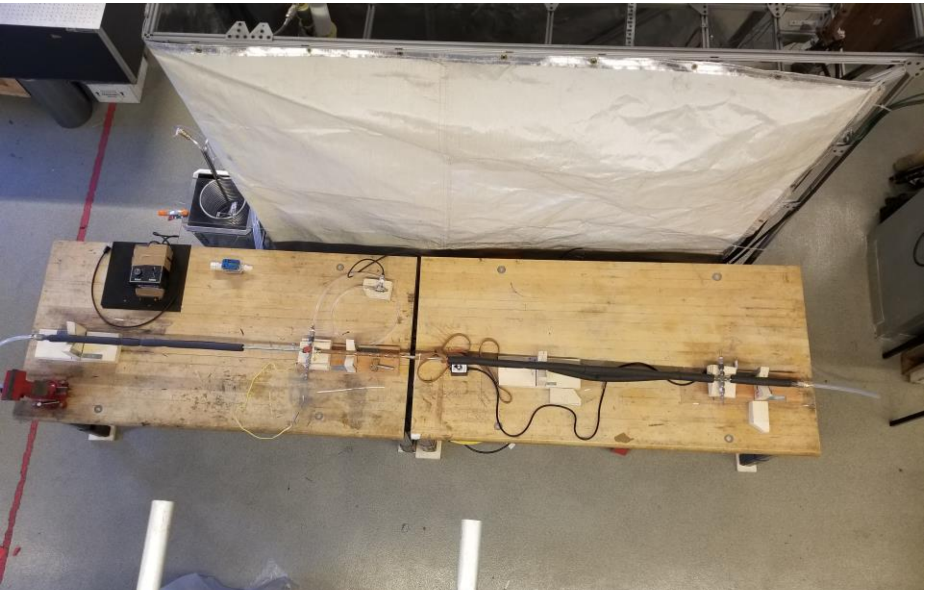


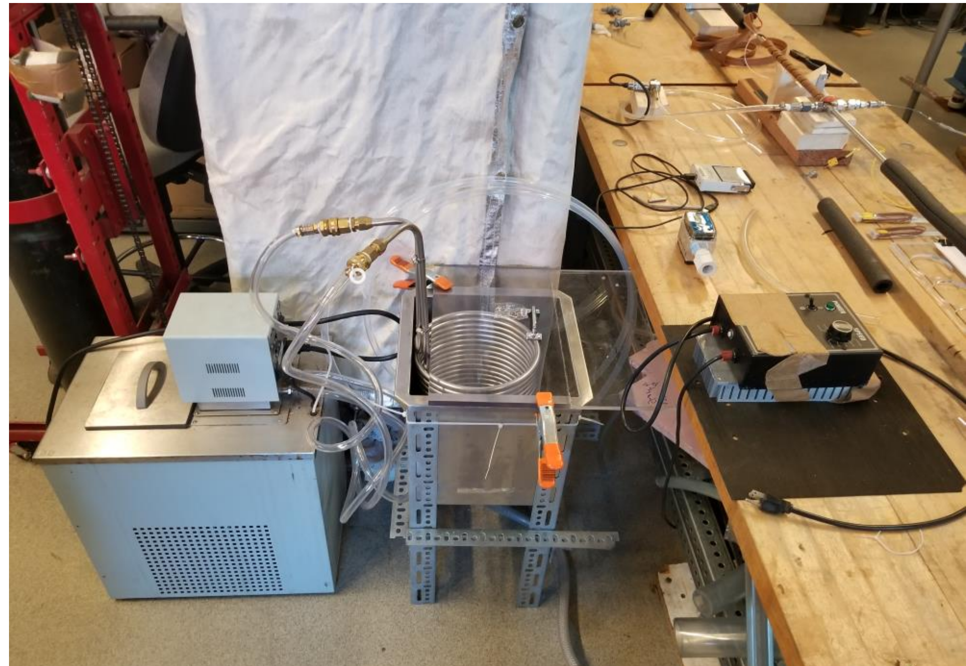
Design Loop

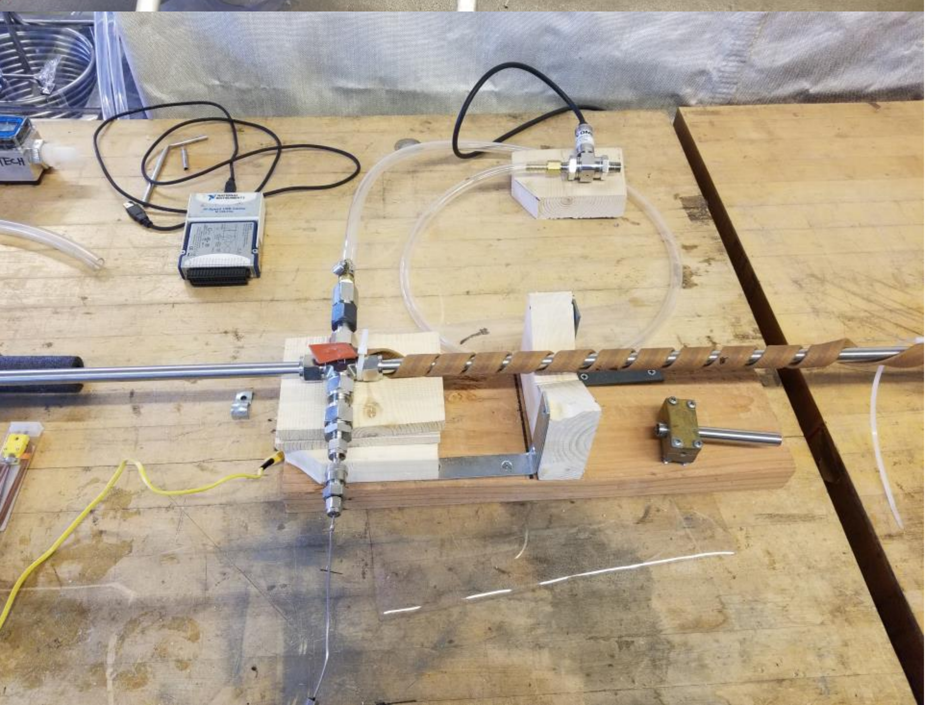


$$Q = \mathbf{h}*A*(T_{surface}-T_{fluid})$$

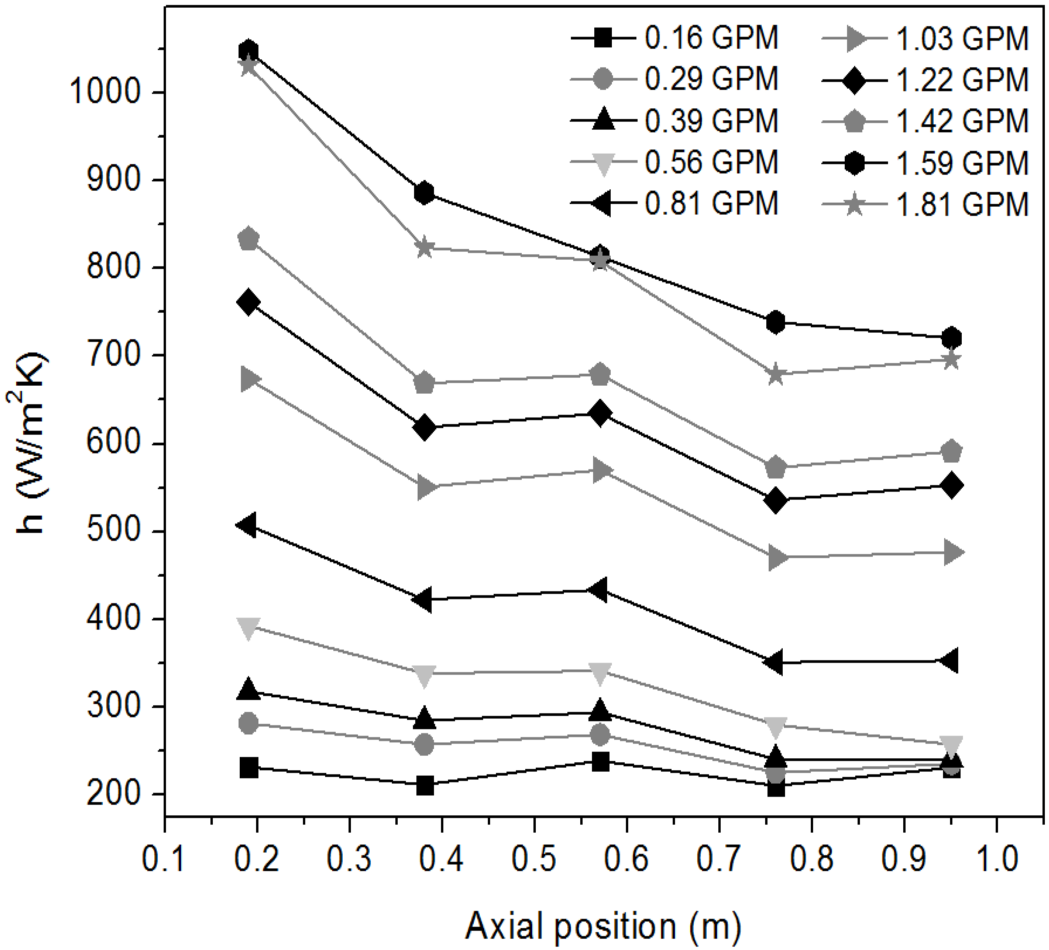
Design Loop







Beeswax results: effect of flow rate

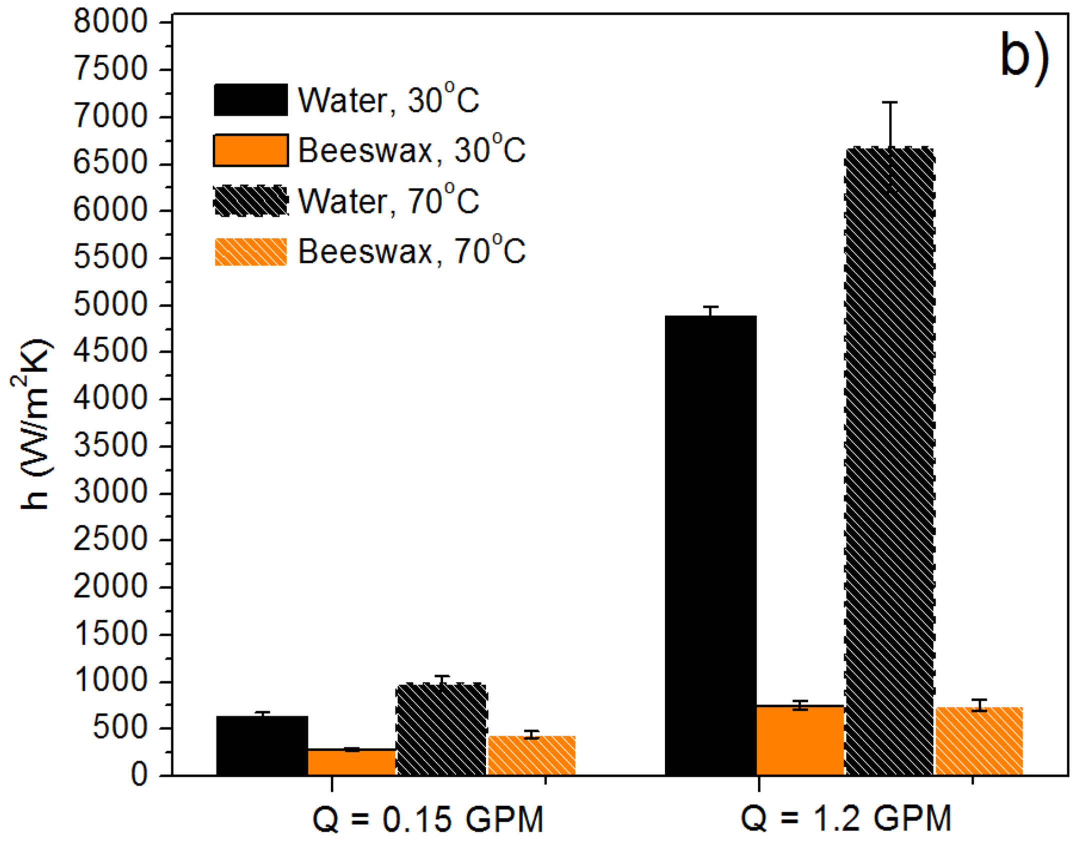


- Higher flow rates show entrance effects
- When reporting the heat transfer coefficient, the average heat transfer coefficient from the five axial locations is used

Anderson et al. [1]

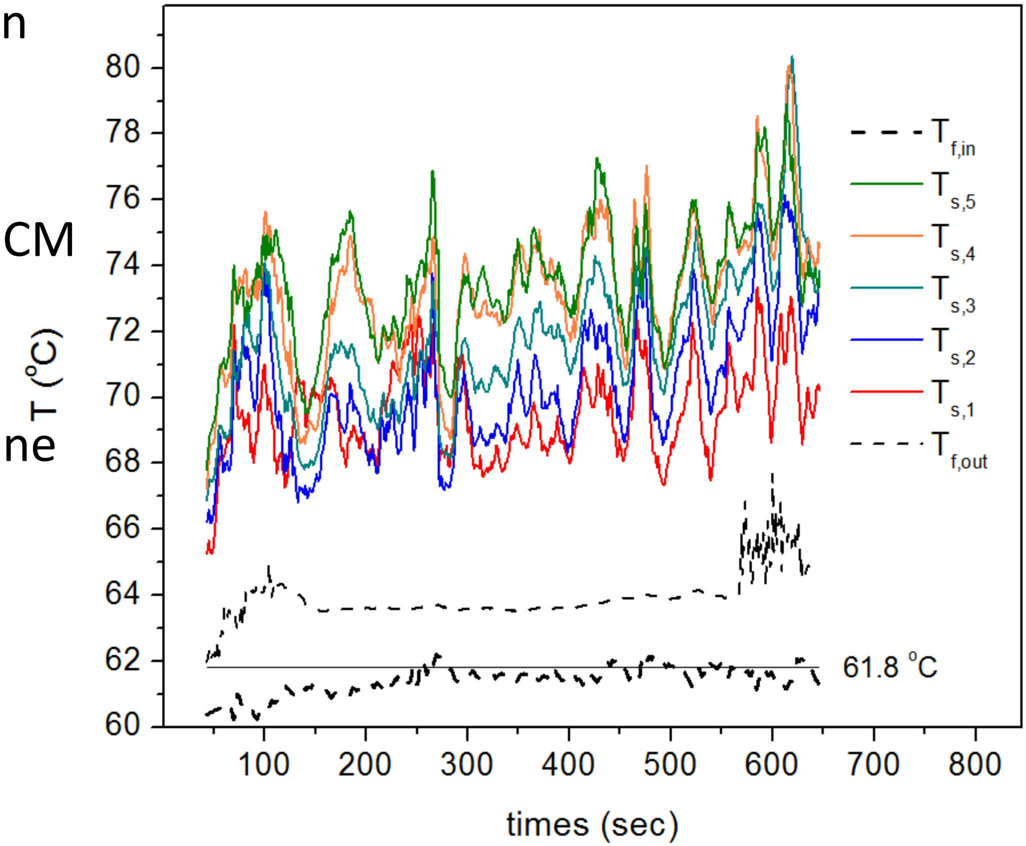
Viscosity jumps from ~20 cP to ~70 cP after the phase change

- Volumetric flow basis: $h_{beeswax} < h_{H2O}$
- Heat transfer coefficient doesn't vary much below and above the melting point for beeswax
- Heat Transfer coefficient was noticeably higher close to the phase change temp. 1,068 W/m^2K (61.8°C) vs 753 W/m^2K (70°C)



Transitional temperature results

- Thermal non-equilibrium effects and unusual instabilities (large amplitude oscillations in the flow rate and heated tube surface temperatures) have been observed at the phase change temperature.
- A radial temperature gradient exist causing non-uniform melting of the PCM particles. The solid particle surface would be partially covered with the liquid PCM and water/surfactant solution, and a three-phase contact line would form on the particle surface, affecting the particle- to-particle interactions and particle behavior.
- Janus Effect?



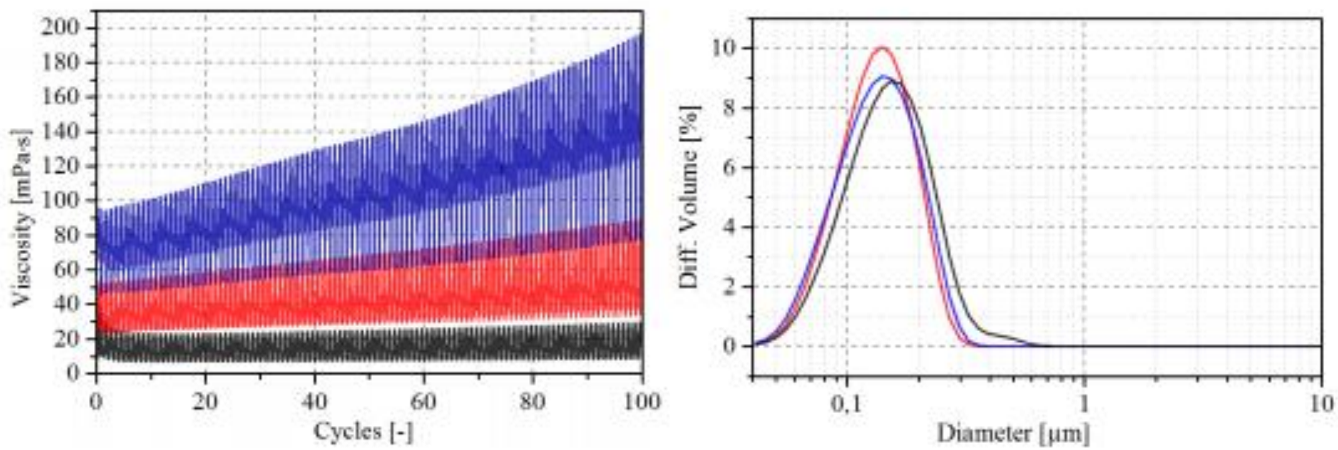
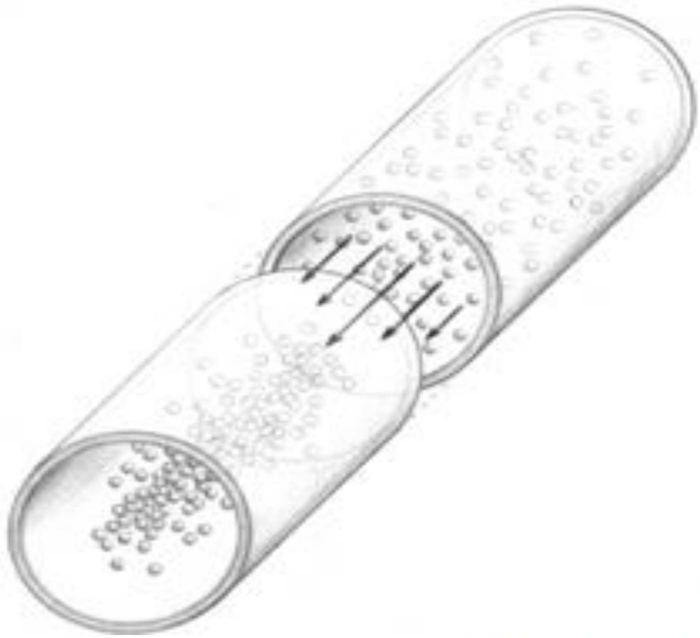


Figure 3: Particle size distribution (right) and viscosity (left) of the emulsion with 30 wt.% (black), 35 wt.% (red) and 40 wt.% (blue) octadecan and 7 wt.% emulsifier in dependence of thermo-mechanical cycles (5 °C - 35 °C; 100 $1 \cdot s^{-1}$)

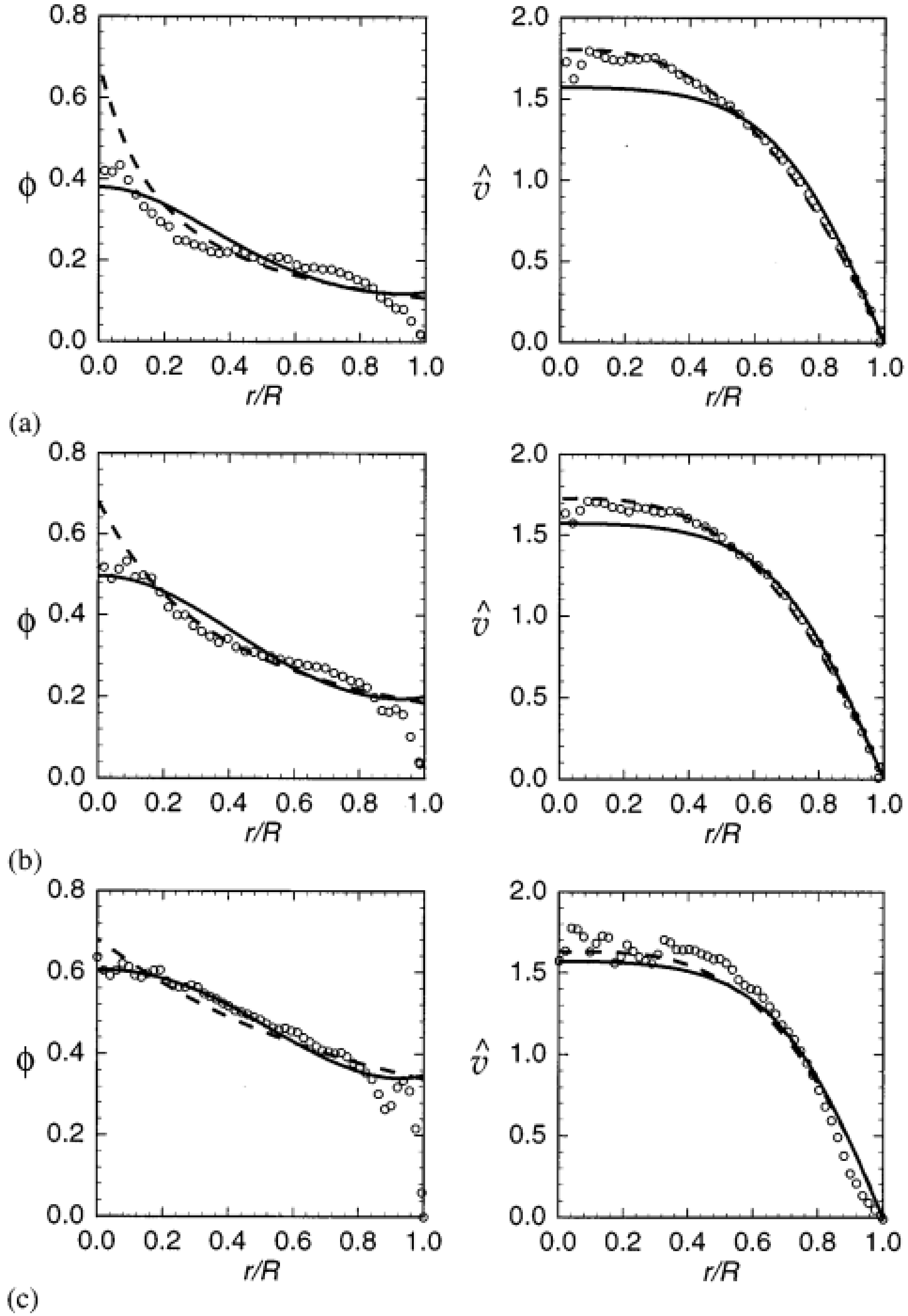
- German collaborators, Niedermaier et al., [6] noticed large differences in viscosity above and below the melting point, increasing with the number of thermal cycles.
- As the PCE is heated and cooled repeatedly, a shear-thickening behavior was also observed, but the physical reasons for these results are unclear.
- In our previous work, the water evaporated causing an increase in viscosity.

Further interests

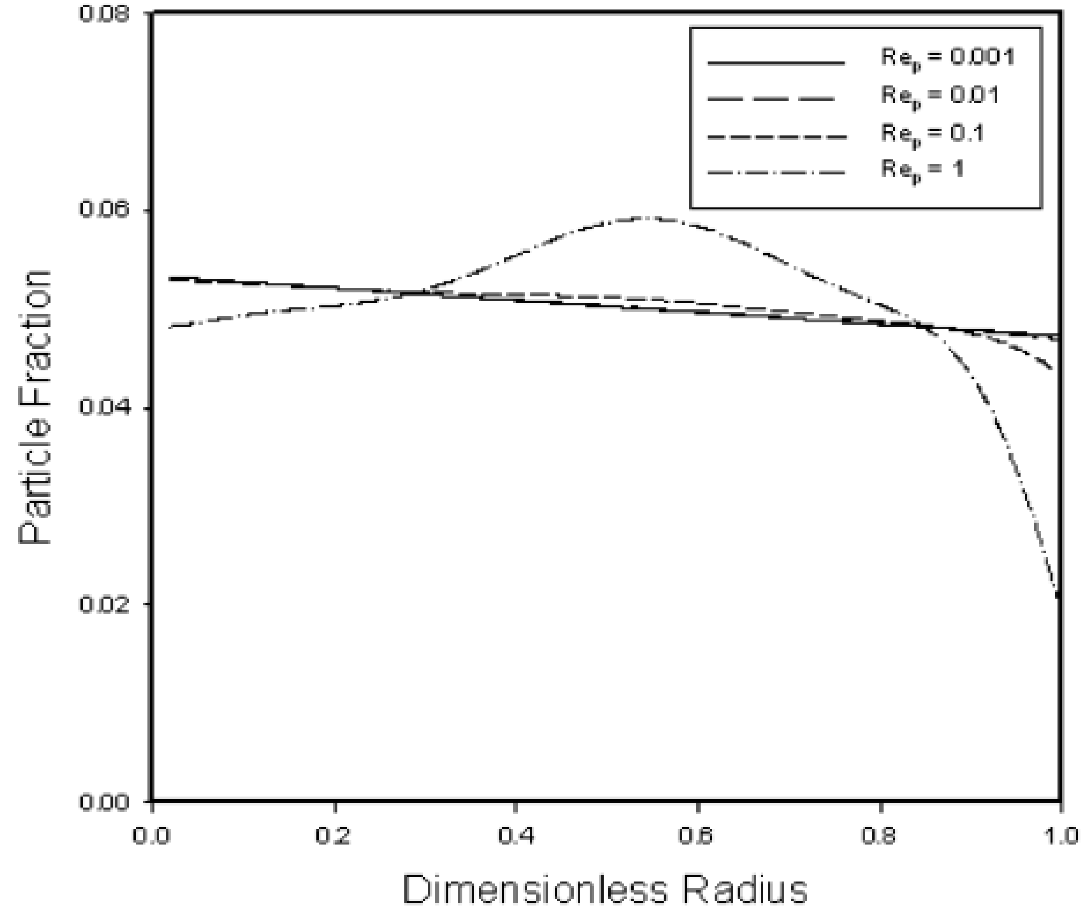


Particle migration from regions of high to low shear rate

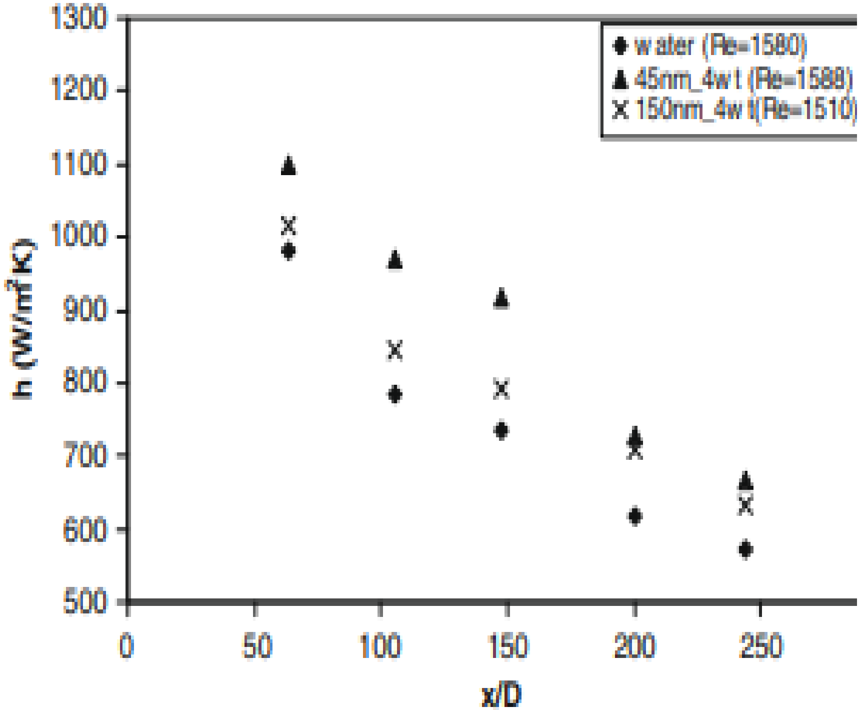
[5] Morris et al.

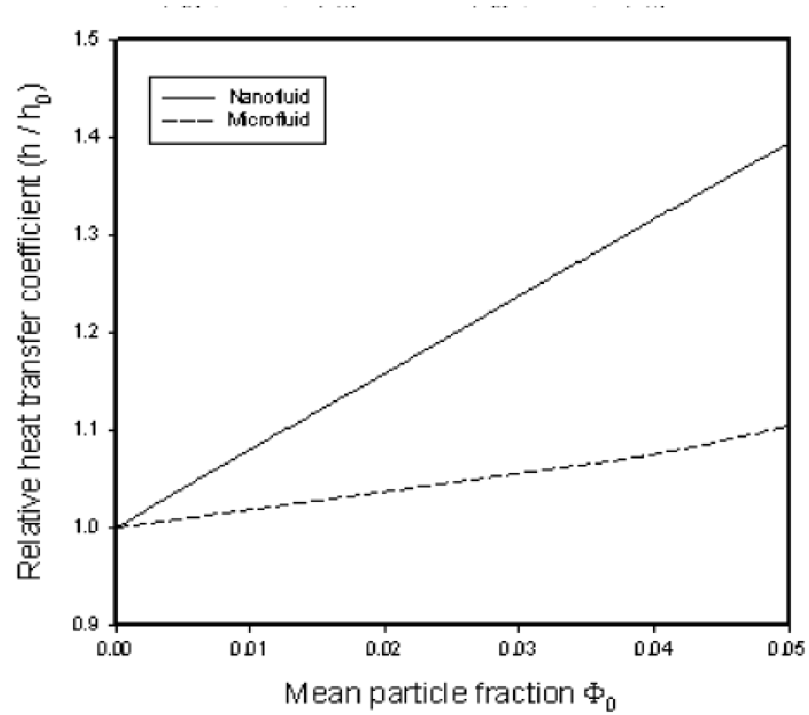


(a) 0.2 vol. fraction
(b) 0.3 vol. fraction
(c) 0.45 vol. fraction
Fully Developed Flow
[7] Hampton et al



Pe= 5 and Vol. Fraction of 0.05 Kang et al [4]





Effect of particle size on heat transfer coefficient at Re ~1550   Anoop et al [2] and Kang et al [4]

Rheo-NMR spectroscopy

- Variable-temperature Rheo-NMR will be performed (Scheler, IPF Dresden) to better understand and control how shear flow affects molecular-level properties and bulk rheology.

  Resolution might be a problem

- Magnetic resonance imaging (MRI) velocimetry experiments under shear flow is expected to reveal quantitative information on how the melting process affects the local velocity profile, yielding valuable insights into the hydrodynamic instabilities.