Capillary μRheoSANS for High Shear Rate, Low Volume Studies

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Applications in industry

\[ \sim 1,000,000 \, \text{s}^{-1} \]
Shear rate and traditional RheoSANS

Shear Rate: \( \dot{\gamma} = \frac{v}{h} \)

\[ \sim 5000 \text{ s}^{-1} \]

7-20 mL Sample
Applications in industry

~1,000,000 s$^{-1}$
Capillary µRheoSANS
Capillary μRheoSANS
Capillary size and velocity

100 μm

20 μm
Capillary fluid flow

Laminar Poiseuille Flow (Newtonian)

\[ \tau = \mu \dot{\gamma} \]

Shear Stress (\(\tau\))  |  Shear Rate (\(\dot{\gamma}\))  |  Velocity

Non-Newtonian

\[ \tau = \mu(\dot{\gamma}) \cdot \dot{\gamma} \]

Shear Stress
Comparison to Slit $\mu$RheoSANS

**High Shear Regions**

- Approximate Scattering Volume [µL]
  - SANS: 100
  - Slit Cell: 10
  - Capillary: 1
Determining physical limits

80.0 v% Glycerol; 100 μm ID; 1.00 m L

$\eta = 57.6 \text{ mPa}^s$

Glycerol-Water Calibration Curve

- Literature
- Our Data
Wormlike micelles

Cross-section

Hydrophilic head

Hydrophobic tail

Viscosity

Shear Rate

Shear Thickening
Newtonian
Shear Thinning
Micelles under high shear

Viscosity Profile of 8 w/v% NaCl & 4.6% SLES Micelle (#3)

- Rheometer Data
- Capillary Data

Capillary SANS Reynolds's Numbers

- Turbulent Flow
- Transient Flow

- 4.6% SLES; 8% NaCl
- 1.15% SLES; 8% NaCl
Small Angle Neutron Scattering (SANS)

\[ Q = \frac{4\pi \cdot \sin(\theta)}{\lambda} \]
2D SANS profiles

Wall $\dot{\gamma} = 0 \text{ s}^{-1}$
WLM (SLES 4.6% NaCl 8%)

Wall $\dot{\gamma} = 1.3 \cdot 10^4 \text{ s}^{-1}$
WLM (SLES 4.6% NaCl 8%)
Micelle alignment factors

Capillary SANS Alignment

Alignment Factor [-]

Wall Shear Rate [s⁻¹]

- 4.6% SLES; 8% NaCl
- 1.15% SLES; 8% NaCl
Wall shear rate scattering isolation

Wall $\dot{\gamma} = 1.3 \cdot 10^4 \text{ s}^{-1}$

Wall $\dot{\gamma} = 6.4 \cdot 10^3 \text{ s}^{-1}$

Isolated High $\dot{\gamma}$ Region

Shear Rate Profile

- Subtracted Region
- Isolated Region

Distance from Center [$\mu$m]

Shear Rate [s$^{-1}$]

$1.3 \cdot 10^4 \text{ s}^{-1}$

$6.4 \cdot 10^3 \text{ s}^{-1}$
Validating results

**Viscosity Profile of 8 w/v% NaCl & 1.15% SLES Micelle (#1)**

\[ \dot{\gamma}_{\text{max}} = 7.5 \cdot 10^5 \, \text{s}^{-1} \]

\[ V_{\text{sample}} = 2 \, \text{mL} \]
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Questions
Extra Slides
Comparison to Slit μRheoSANS

**Slit Cell\(^1\)**

Top

L = 33 mm

H = 0.1 mm

Neutron Beam

**Isolated High Shear Rate Regions**

- Capillary
- Slit Cell

**Isolated High Shear Rate Volume for 5x13 mm Aperture**

- Capillary [100 μm ID, 12 Channels]
- Capillary [100 μm ID, 4 Channels]
- Slit Cell [100 μm Height]
Comparison to Slit µRheoSANS

Capillary

High $\gamma$

Slit Cell

High $\gamma$
Important equations

\[ \tau = \mu \dot{\gamma} \]
Shear Stress

\[ \tau = \frac{\Delta P R}{2L} \]
Capillary Shear Stress

\[ v = \frac{\Delta P R^2}{4\mu L} \left[ 1 - \left( \frac{r}{R} \right)^2 \right] \]
Capillary Velocity

\[ \mu = \frac{\Delta P \pi R^4}{8LQ} \]
Capillary Viscosity (Hagen-Poiseuille)

\[ \dot{\gamma} = \frac{4Q}{\pi R^3} \]
Apparent Wall Shear Rate

\[ \dot{\gamma}_{WR} = \dot{\gamma}_a \left[ \frac{1}{4} \left( 3 + \frac{d \ln \dot{\gamma}_a}{d \ln \tau} \right) \right] \]
Corrected Wall Shear Rate (Weissenberg-Rabinowitsch)

\[ Re = \frac{\rho D Q}{A\mu} \]
Reynold’s Number
Micelle alignment factors

Capillary SANS Alignment

- 4.6% SLES Wall Shear Rate
- 1.15% SLES Wall Shear Rate
- 4.6% SLES Isolated Shear Rate
- 1.15% SLES Isolated Shear Rate

Alignment Factor [-]

Shear Rate [s⁻¹]

10⁰  10¹  10²  10³  10⁴  10⁵  10⁶
Stability of micelle pressure drops

Stability of 6 w/v% NaCl & 4.6% SLES Micelle (#6) Over Time by Flow Rate [mL/min]
Other capillary jet video