


# On-line Rheometry of Complex Process Fluids

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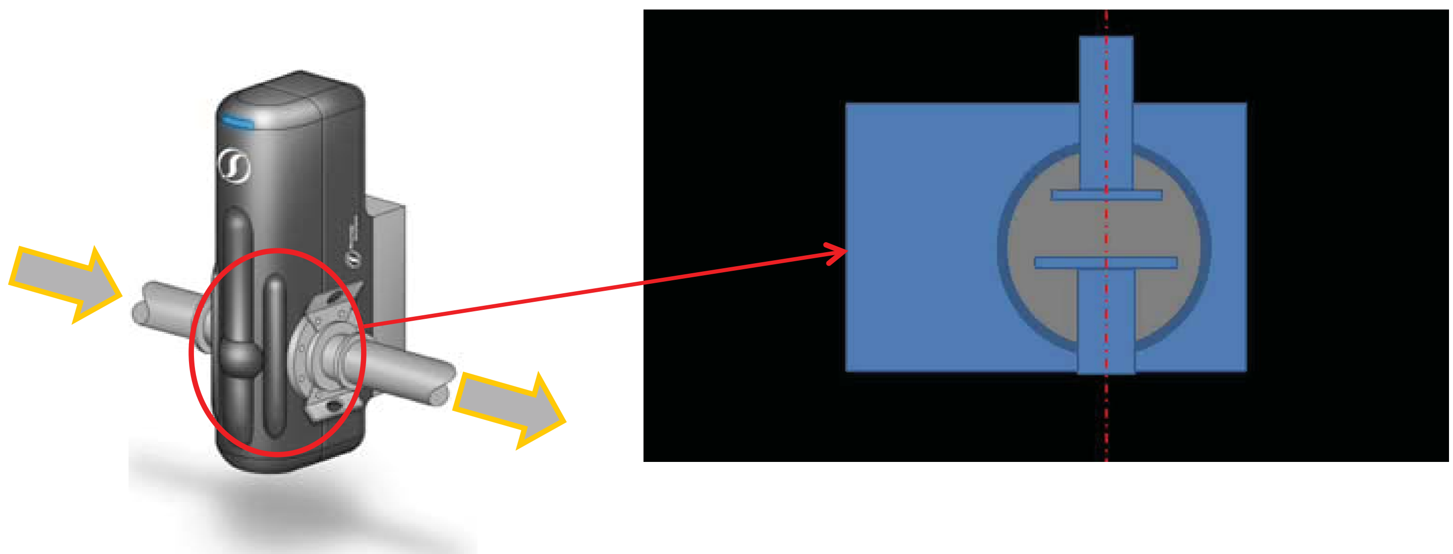
# Principle of Operation

- Small amplitude oscillatory squeeze flow
- Provides viscoelastic frequency response of process fluid between 1 and 100 Hz, on-line and in real-time
- OLR-Software allows monitoring and control of process operations, using standalone software (SOLR), or factory PLC



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# Background Theory

Gap z varying about an equilibrium position h with an angular frequency $\omega$ in time t, is $z = h + \varepsilon e^{i\omega t}$

Total normal force, $p = \frac{3\pi i \omega \varepsilon a^4 \eta^* e^{i\omega t}}{2h^3} \{1 - (\alpha h)^2/10\}$, $\alpha = \sqrt{(i\omega\rho/\eta^*)}$ **

$p_0$ = amplitude; c = phase lag; $\varepsilon(\textit{separation between the plates}) = \epsilon h$; $a$ = radius of the top plate; $\eta^*$ = complex viscosity

$G' = \frac{2h^3 p_0 \cos c}{3\pi\varepsilon a^4} + \frac{\omega^2 \rho h^2}{10}$, and
$G'' = \frac{2h^3 p_0 \sin c}{3\pi\varepsilon a^4}$ **

Knowing the geometric parameters $h$, $a$, and $\varepsilon$ and the upper plate displacement profile, then measuring $p_0$ and $c$, the G', G'' can be estimated using oscillatory squeeze flow.

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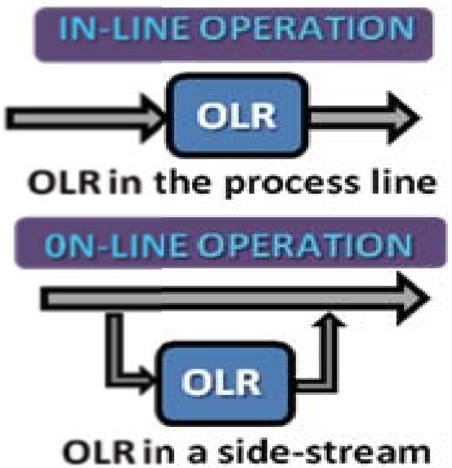
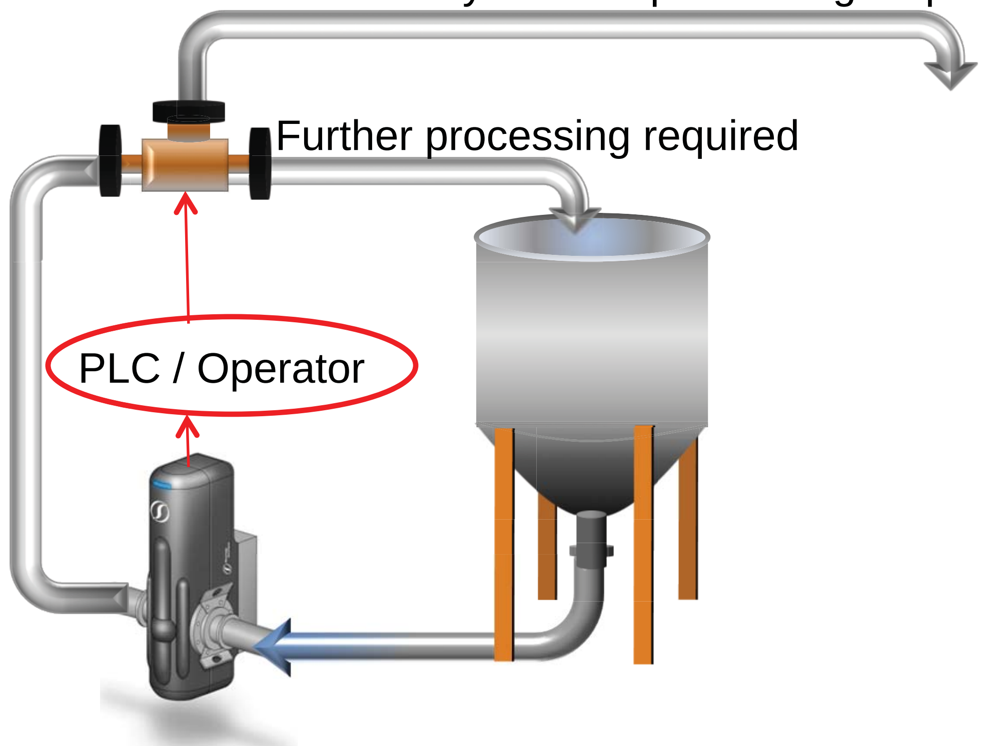
** Bell D, Binding D, Walters K. Rheologica acta. 2006;46(1):111-121.

# Installation




OLR can be directly connected in the main process pipe-line or in a side loop, as necessary.

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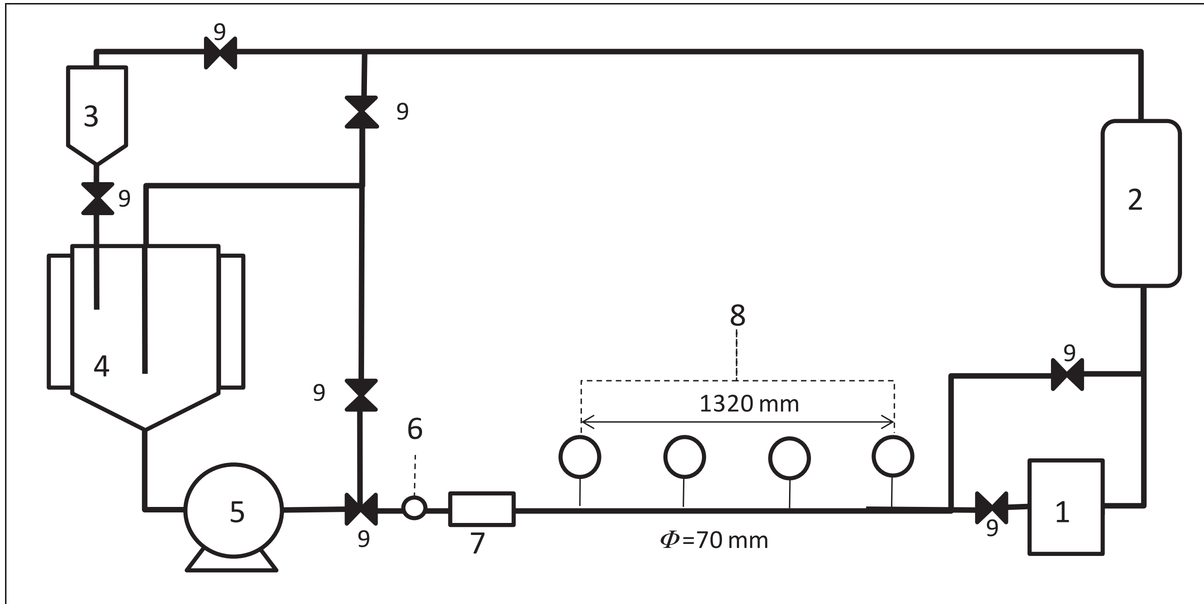
# Experimental

Pipe Loop:




Schematic of the pipe-loop arrangement 1: OLR, 2: Flowmeter, 3: Measuring tank, 4: Bulk tank, 5: Mono pump, 6: Online Viscometer, 7: Inspection window, 8: Pressure transducers, 9: Valves

OLR: Strain ≈ 0.75%, Swept (1-100Hz) Sine wave.

Lab. rheometer: HAAKE MARS III (ThermoFisher Scientific)

In-line viscometers: ProLinePromass (Endress& Hauser) - $\gamma \approx 4500 s^{-1}$ ,
VA Series (Marimex) - $\gamma \approx 3500 s^{-1}$

Test Material: 2.5% solution of carboxymethyl cellulose (CMC) in water.

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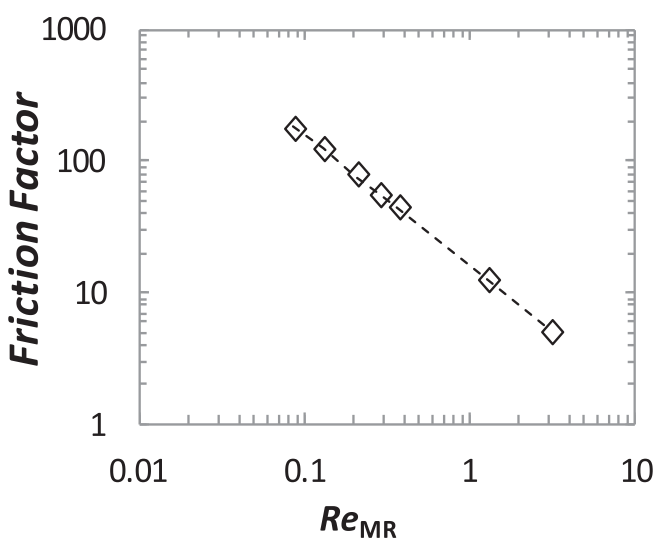
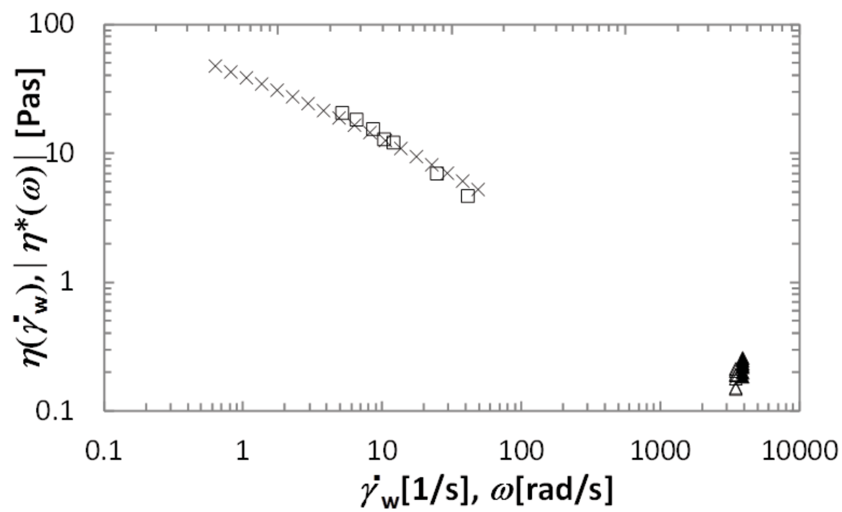
# Results: Pipe-loop & process viscometers




Experimental f vs. Re (Metzner-Reed) ([illegible]).

The line in the figure is $16/Re_{MR}$.

Viscosity measured using:

- DP in a flowing pipe ([illegible])
- Marimex Viscoscope ([illegible])
- E&H Proline flowmeter ([illegible])
- h* - laboratory rheometer ([illegible])

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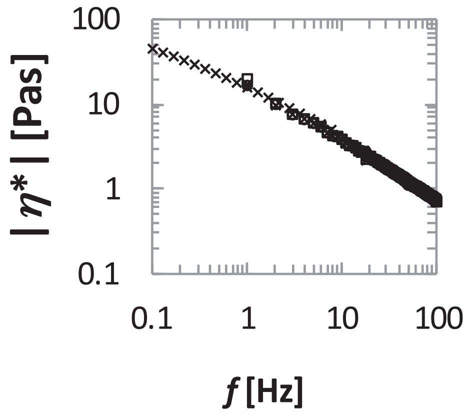
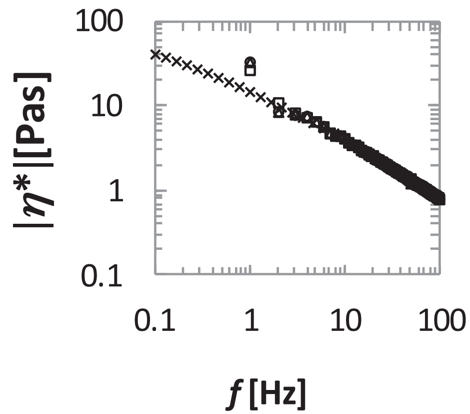
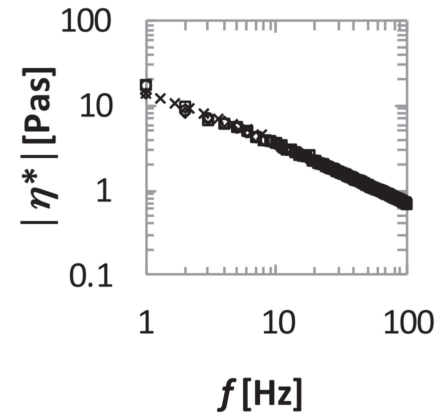
# Results: OLR & Lab Rheometer




(a)1500 kgs/hr
0.11m/s




(b)1900 kgs/hr
0.14m/s




(c)2900 kgs/hr
0.21m/s

Results of experiments conducted at various flow-rates.

Laboratory rheometer represented using cross symbols (⊠).

Other symbols represent measurements made by the OLR for repeated experiments at a fixed flow-rates.

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# Conclusions

Conclusions:

- Pipe-loop delivering reliable data.
- In-line viscometers have some scatter but qualitatively provide an indication of the material properties.
  - Difficult to validate quantitatively.
- OLR performs well.
  - Quantitative agreement with lab rheometer and pipe-loop data.
  - Flow and no-flow conditions.
  - Better response time than laboratory rheometers, better fingerprinting than on-line viscometers.

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# Acknowledgement

***The OLR commercialisation project at Rheology Solutions is part-funded by the Australian Government Commercialisation Australia ESC Funding from Dept. Innovation, Industry & Science.***

*the* **OLR** *keeps your process in line*

Rheology Solutions

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