Elasticity and particle induced flow instabilities and transitions in Taylor-Couette Flows (TCF)

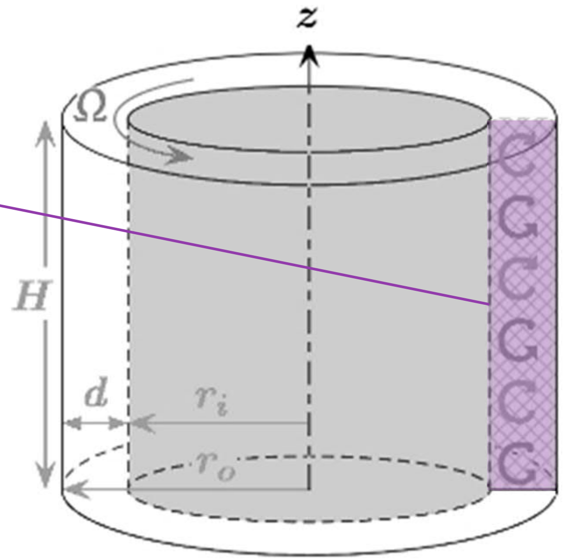
UCL

COral

Common geometry

- Wide spectrum of instabilities
- Theoretical predictions
- Accessible to numerical simulations
- Related to rheometer configuration
- Mixing device

Taylor 1923
Andereck et al. 1986
Dutcher & Muller 2009
Grossman et al 2016



Case studied: fixed outer cylinder, inner cylinder rotating at speed Ω

Nominal shear rate: $\dot{\gamma} = \frac{\Omega r_i}{d}$, in s^{-1}

Geometric parameters
Inner and outer radius: $r_i = 21.65$ mm, $r_o = 27.92$ mm
Gap: $d = r_0 - r_i = 6.27$ mm
Radius ratio: $\eta = \frac{r_i}{r_o} = 0.78$
Aspect ratio: $\Gamma = \frac{H}{d} = 21.5$

Non Newtonian Polymer solutions

Viscoelasticity:
- Polymer elastic deformations
- Elastic and elasto-inertial instabilities (Groismann & Steinberg 1996,1997,1998)
- Numerical studies (Lange & Eckhardt 2001)

Shear thinning:
- Stability, flow structure, mixing (Cagney & Balabani, 2019a,b) ← CORral
- Studied numerically (Alibenyahia et al. 2012, Khali et al 2013 …)
- Lack of experimental data in the Taylor-Couette system

Non-colloidal particle suspensions
- Recent focus in Newtonian solvents (Majii et al 2018, Ramesh et al. 2019, Ramesh and Alam 2020)

Rheological measurements

ARES rheometer, Couette geometry

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Elastic time scale (Oscillatory shear)

$$t_e = \frac{2\pi}{\omega_c} \text{ such that } G'(\omega_c) = G''(\omega_c)$$

G': elastic/ storage modulus [Pa]

$G"$: Viscous/ loss modulus [Pa]

Carreau model (Steady shear)

$$\frac{\mu - \mu_\infty}{\mu_0 - \mu_\infty} = \left(1 + (\lambda\dot{\gamma})^2\right)^{\frac{n-1}{2}}$$

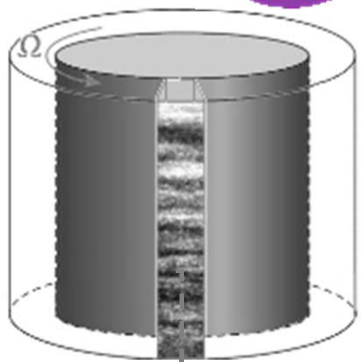
μ, μ_∞, μ_0: Nominal, infinite and zero shear rate viscosities [Pa.s]
λ: Carreau time scale [s]
n: shear thinning index [-]
$\dot{\gamma}$: Nominal shear rate [1/s]

Flow visualisation

Flow visualisation method:

1. Seeding with Mica flakes
(Dutcher & Muller 2009, Majji et al. 2018)
2. Flow maps and Re-space diagrams:
3. FFT and Re-frequency diagrams

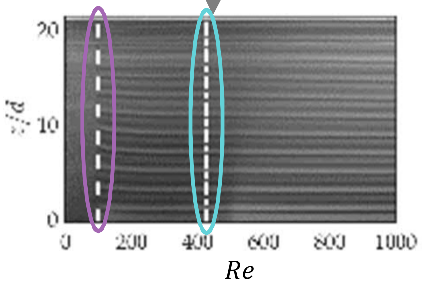
Cylinder acceleration ("ramp up") or deceleration ("ramp down")

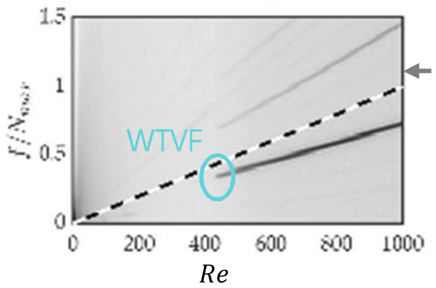


Width averaging

For varying $Re = \frac{\rho \Omega r_i d}{\mu}$

FFT

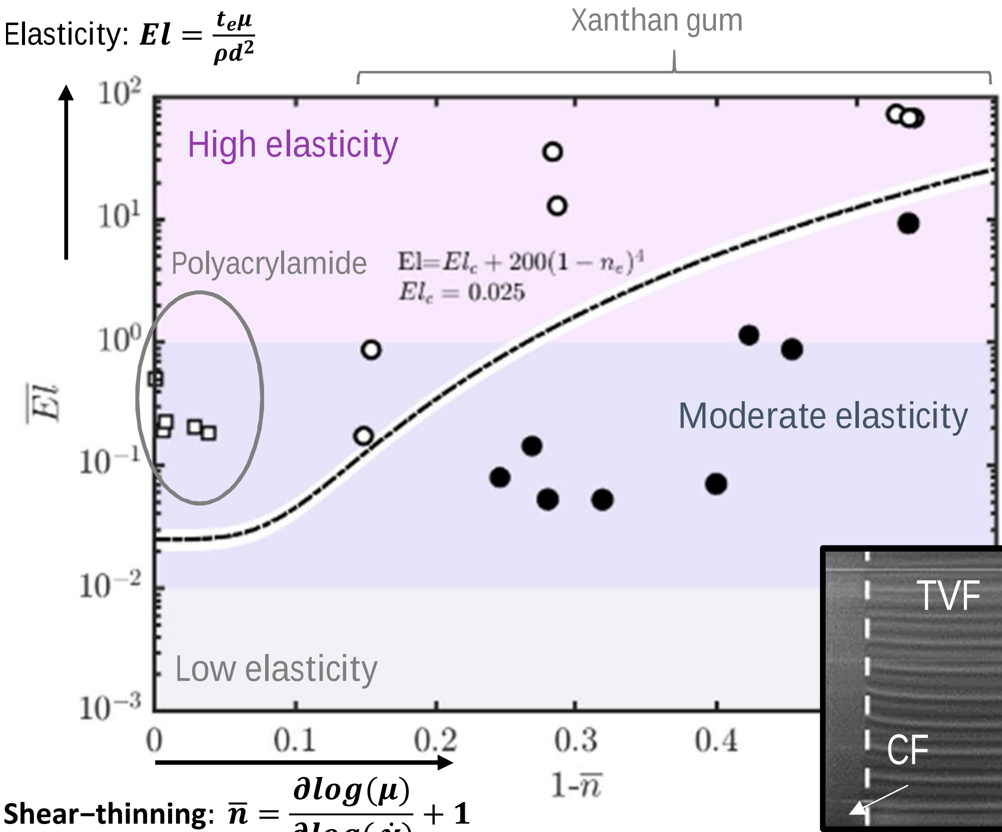




CF: Couette Flow
TVF: Taylor Vortex Flow
FFT: Fast Fourier Transform
WTVF: Wavy Taylor Vortex Flow

Overview

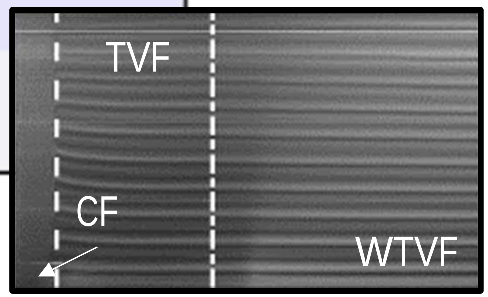
Elasticity: $\boldsymbol{El} = \frac{t_e\mu}{\rho d^2}$



Shear–thinning: $\overline{n} = \frac{\partial log(\mu)}{\partial log(\dot{\gamma})} + 1$

Polymer solutions
- Nature
- Molecular weight
- Solvent viscosity
- Concentration

Newtonian-like



“Newtonian-like” shear thinning fluid

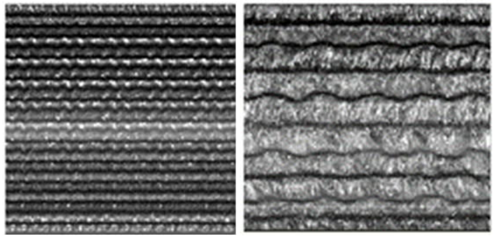
Cagney et al. – Submitted to JFM

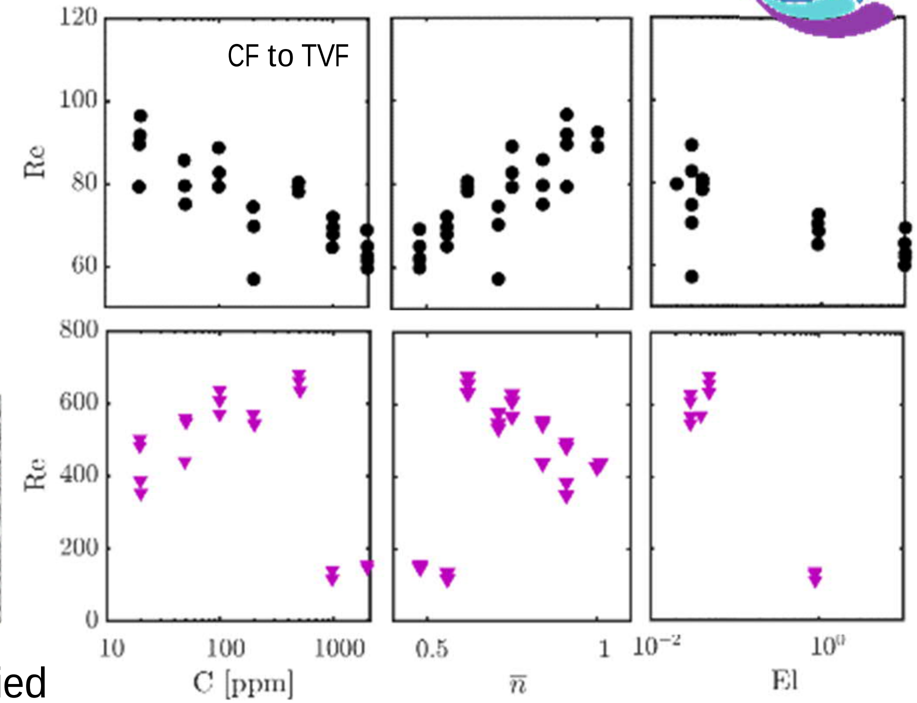
CF to TVF transition
Destabilisation

TVF to WTVF transition
Non monotonic trends

0 ppm
$Re = 700$

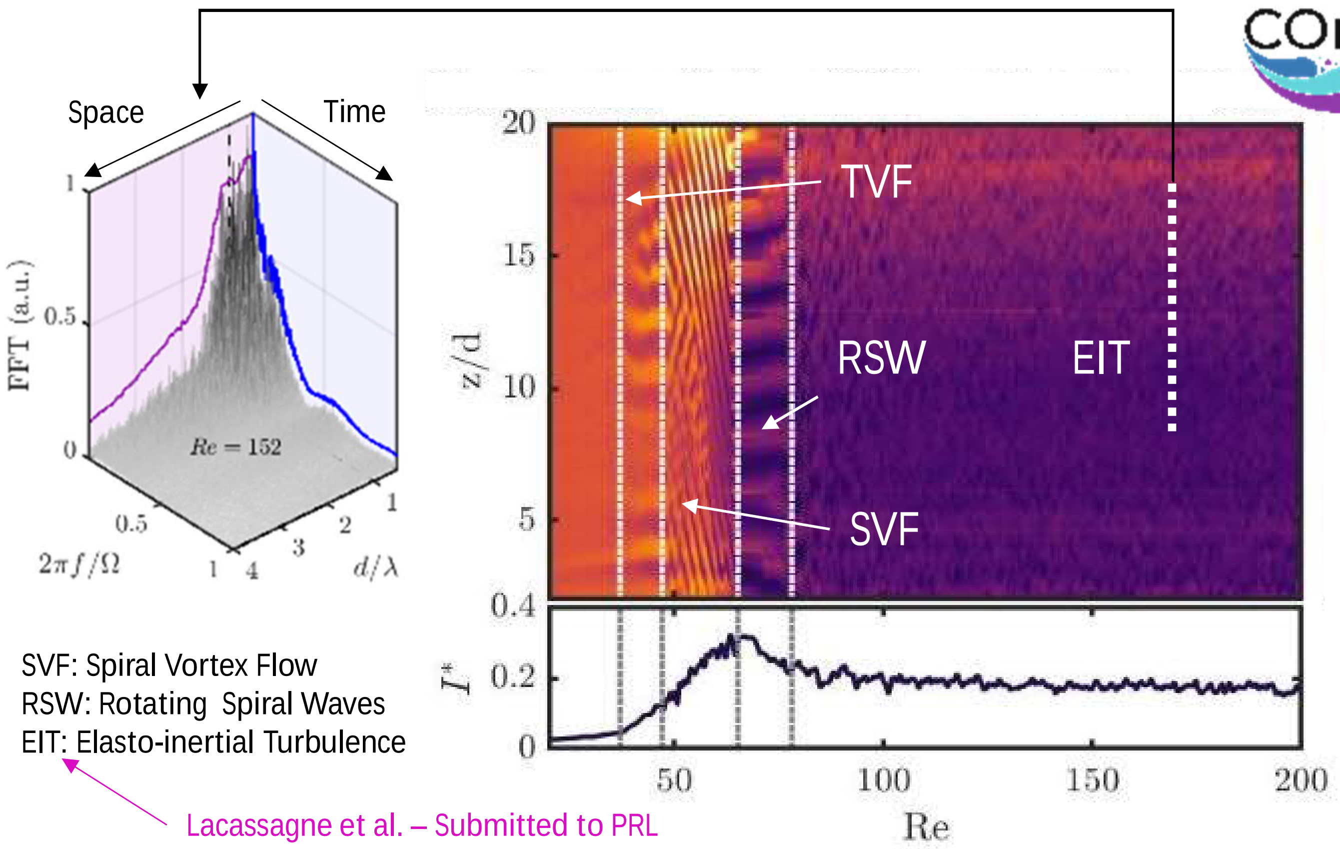
2000 ppm
$Re = 1000$





Nature of the WTVF modified
Jet differentiation, reduced frequency with increasing shear thinning or elasticity

Transition to EIT with elasticity



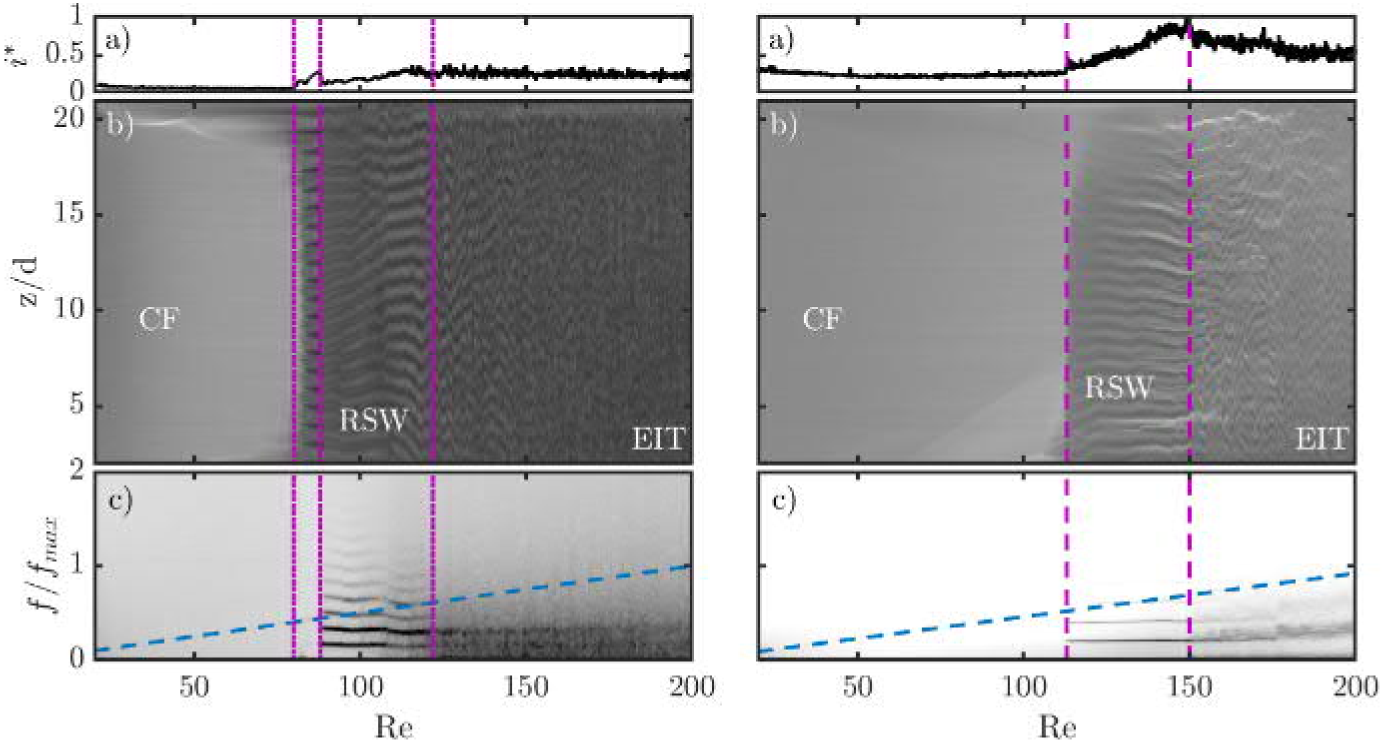
SVF: Spiral Vortex Flow
RSW: Rotating Spiral Waves
EIT: Elasto-inertial Turbulence

Lacassagne et al. – Submitted to PRL

Towards particle suspensions

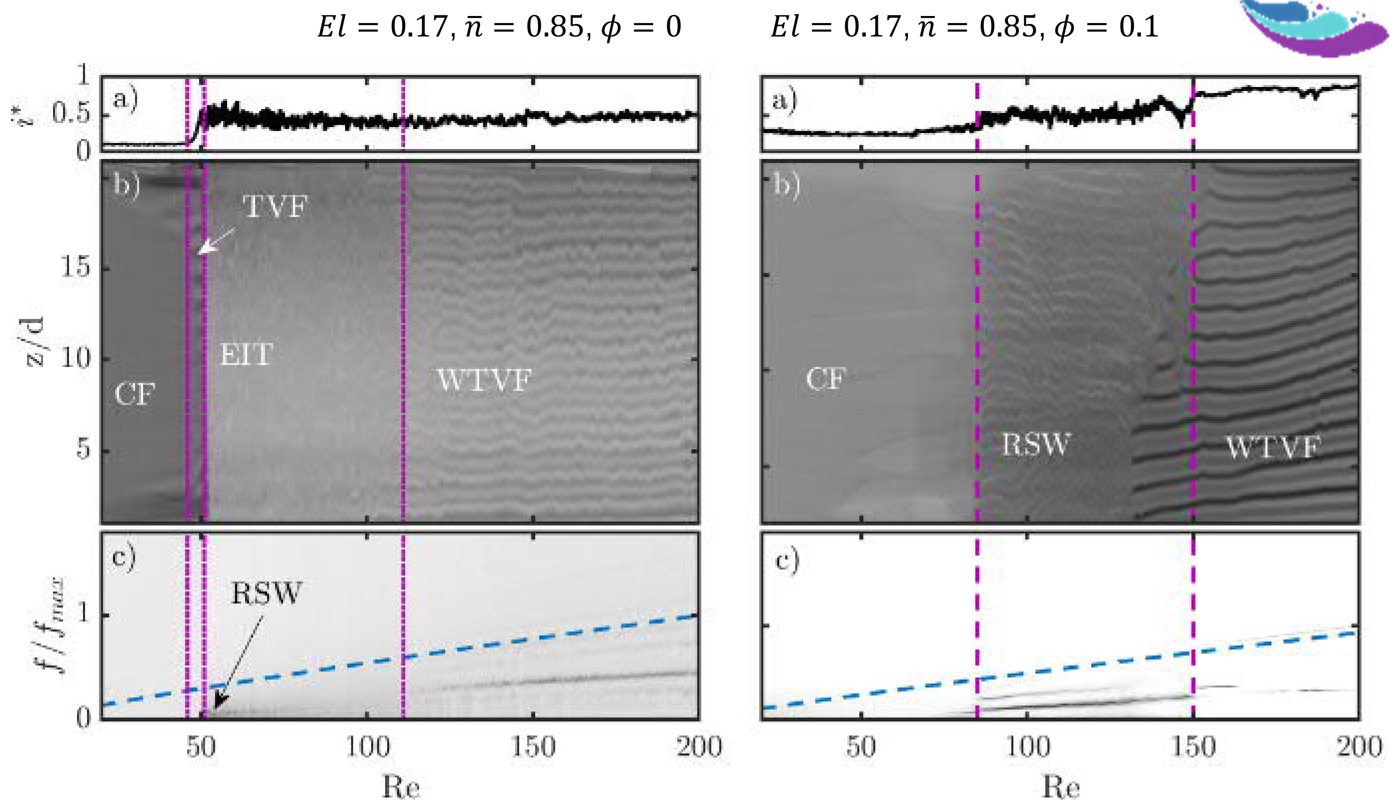
Boger fluid (PAAM, 200ppm)

$El = 0.22, \bar{n} = 1, \phi = 0$ $El = 0.22, \bar{n} = 1, \phi = 0.1$



Towards particle suspensions

Shear-thinning, elastic fluid (XG, 200ppm)



Key points

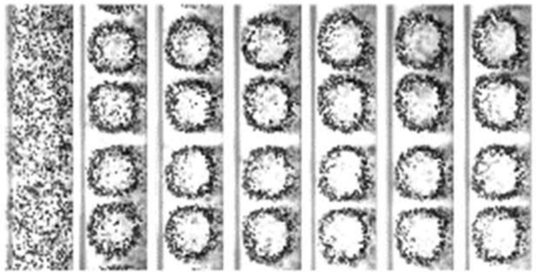
Take home message

- Complex fluids, complex flows
- Competition of rheological effects
- Consequences on mixing

Perspectives:

- What are the mechanisms involved ?
- Mixing quantification
- Towards dense suspensions
  (Papadopoulou et al. 2020)
- Particle migration: inertial, elastic ?

Majji and Morris 2019



Rida et al. 2019