Flocculant dilution effects on flocculation in mineral processing

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Those involved in this work

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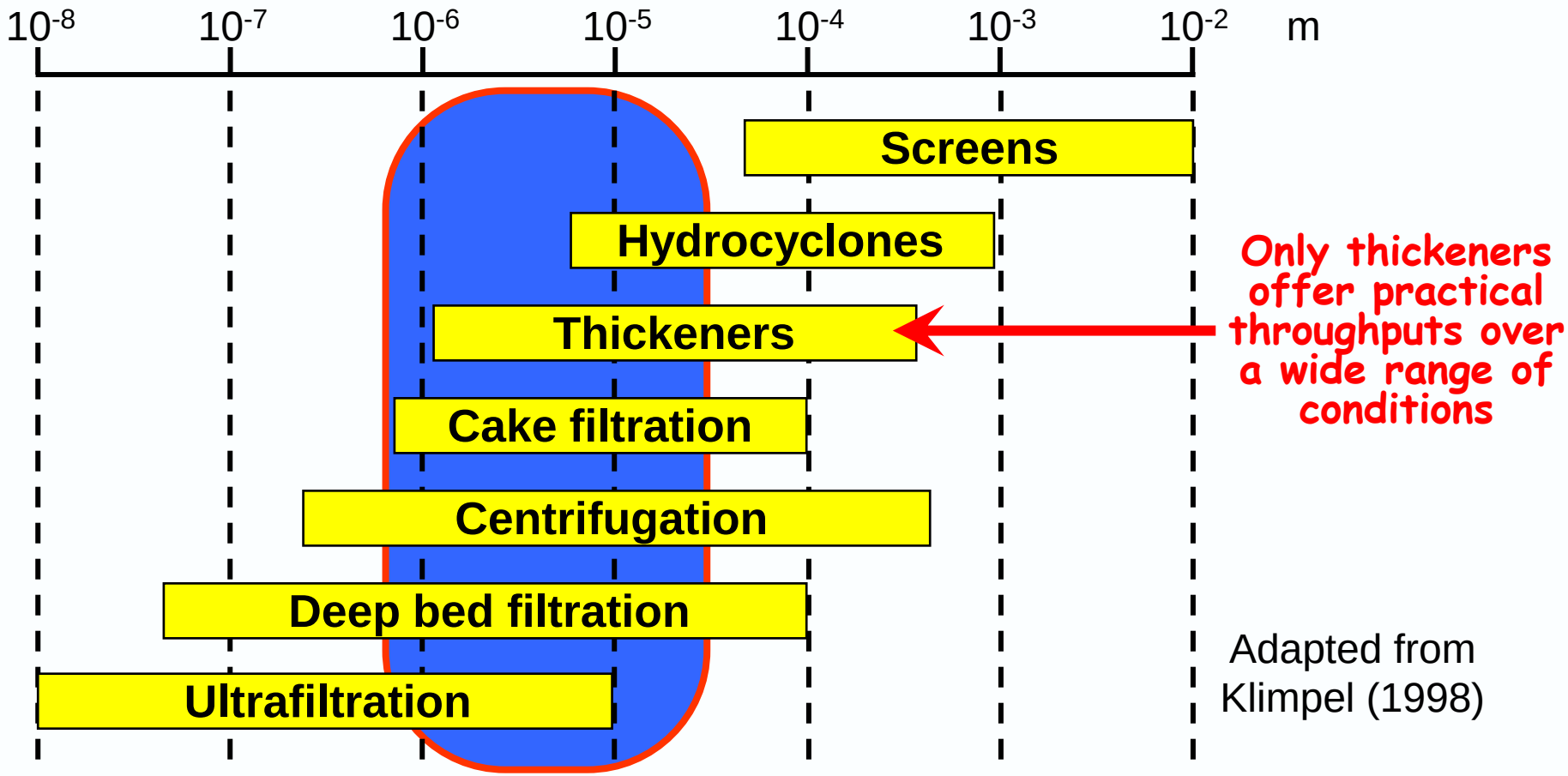
  - Andrew Owen.
  - Alton Grabsch.
  - Jean Swift (retired).
  - John Farrow.
  - Phillip Fawell.

Work largely conducted through the AMIRA P266 "Improving Thickener Technology" series of projects, stages P266C, D, E and F

Particle sizes for solid-liquid separation

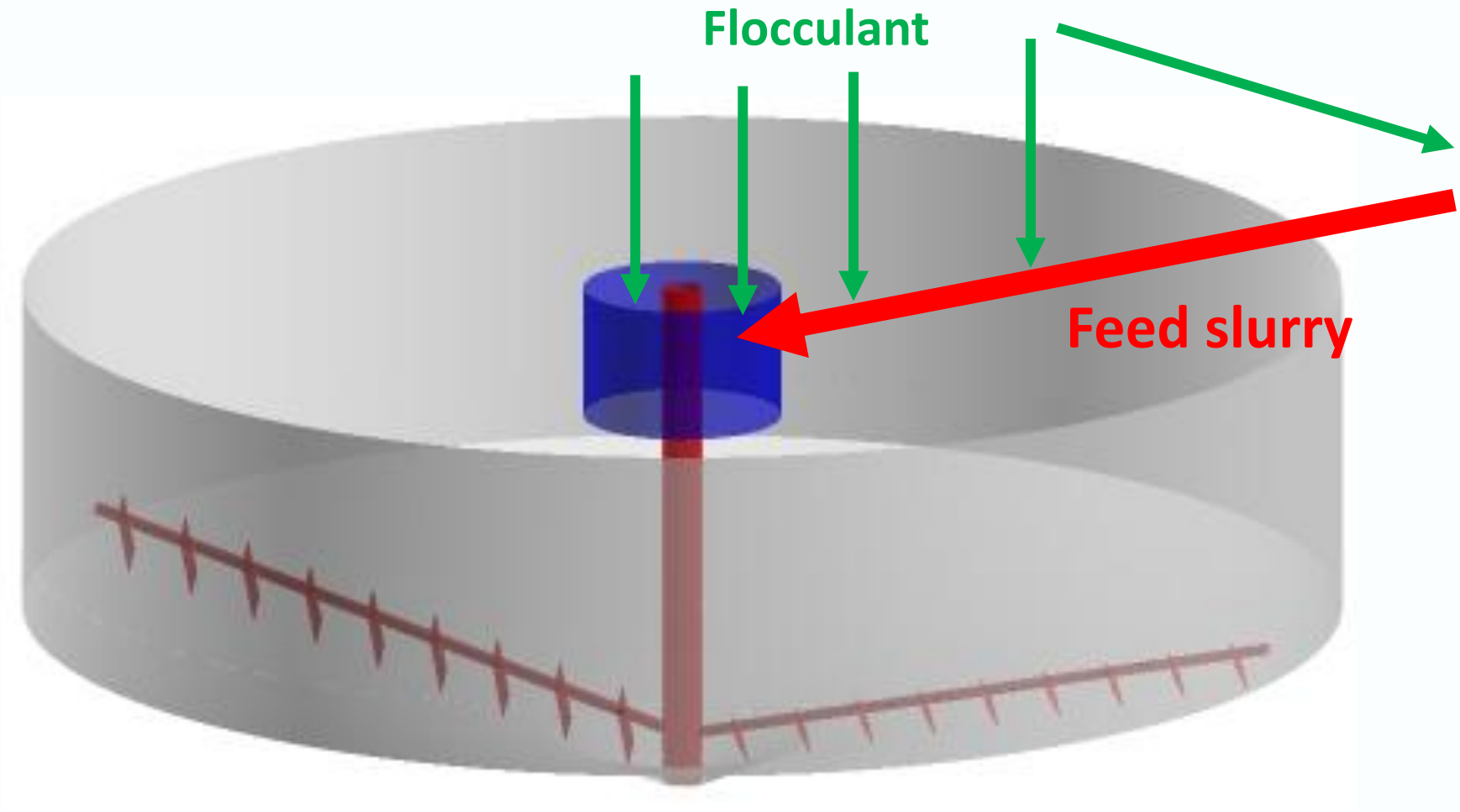


Adapted from Klimpel (1998)

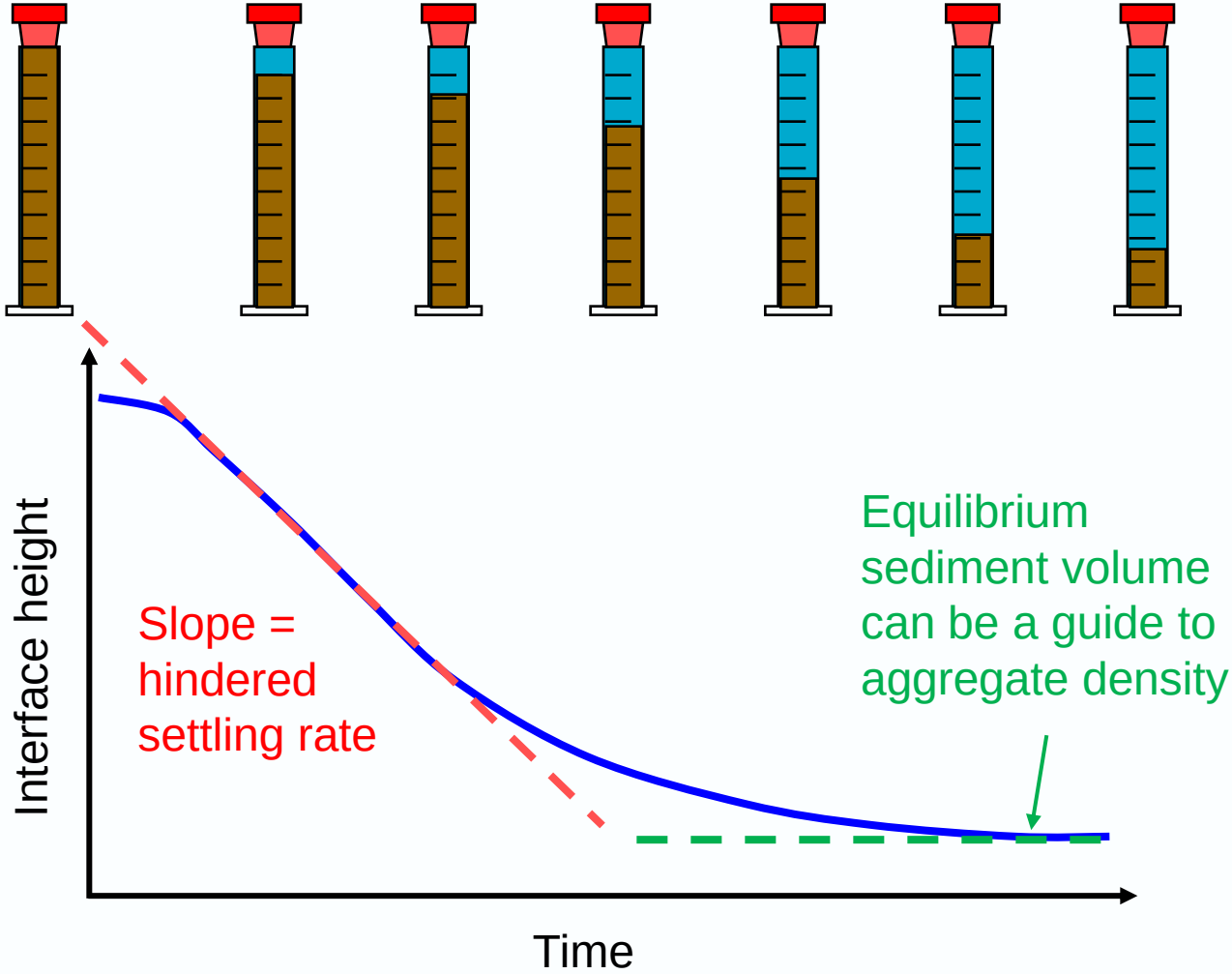
Why flocculate?

- Settling rates of unflocculated solids <1 m h^{-1}.
- Rise velocities in typical thickeners:
  - 1-2 m h^{-1} in clarifiers.
  - 4-6 m h^{-1} in conventional units.
  - 8-10 m h^{-1} (if not higher) in many modern units.
- Aggregation is required to exceed the rise velocity:
  - Can be partially achieved from natural aggregation at high ionic strength, especially for sub-micron solids, but not sufficient.
  - Bridging flocculation by high molecular weight synthetic flocculants.
- Flocculants are typically acrylamide/acrylate copolymer solutions.
- Aggregate breakage is essentially irreversible:
  - Requires careful optimisation of flocculation conditions.

Thickeners in mineral processing



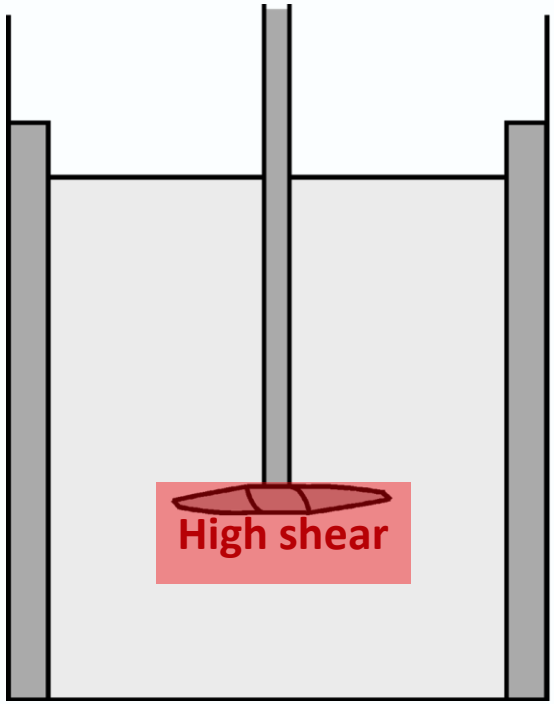
Cylinder tests: a necessary evil

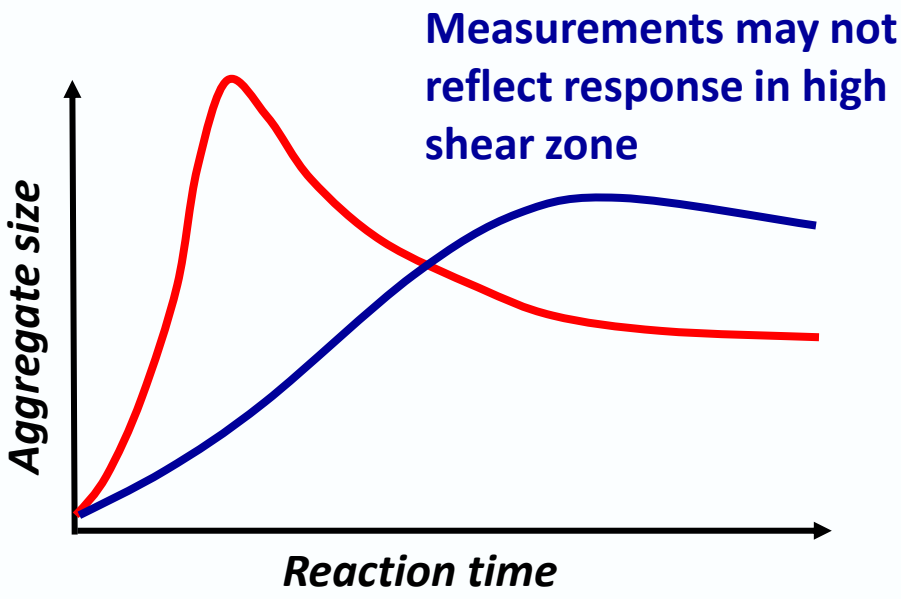


Flocculant selection and testing

Thousands of papers dealing with the flocculation process and the effects of flocculants. *>90% are "very poor" to "#$&%".*

- Stirred beaker tests are largely irrelevant for feedwell flocculation.



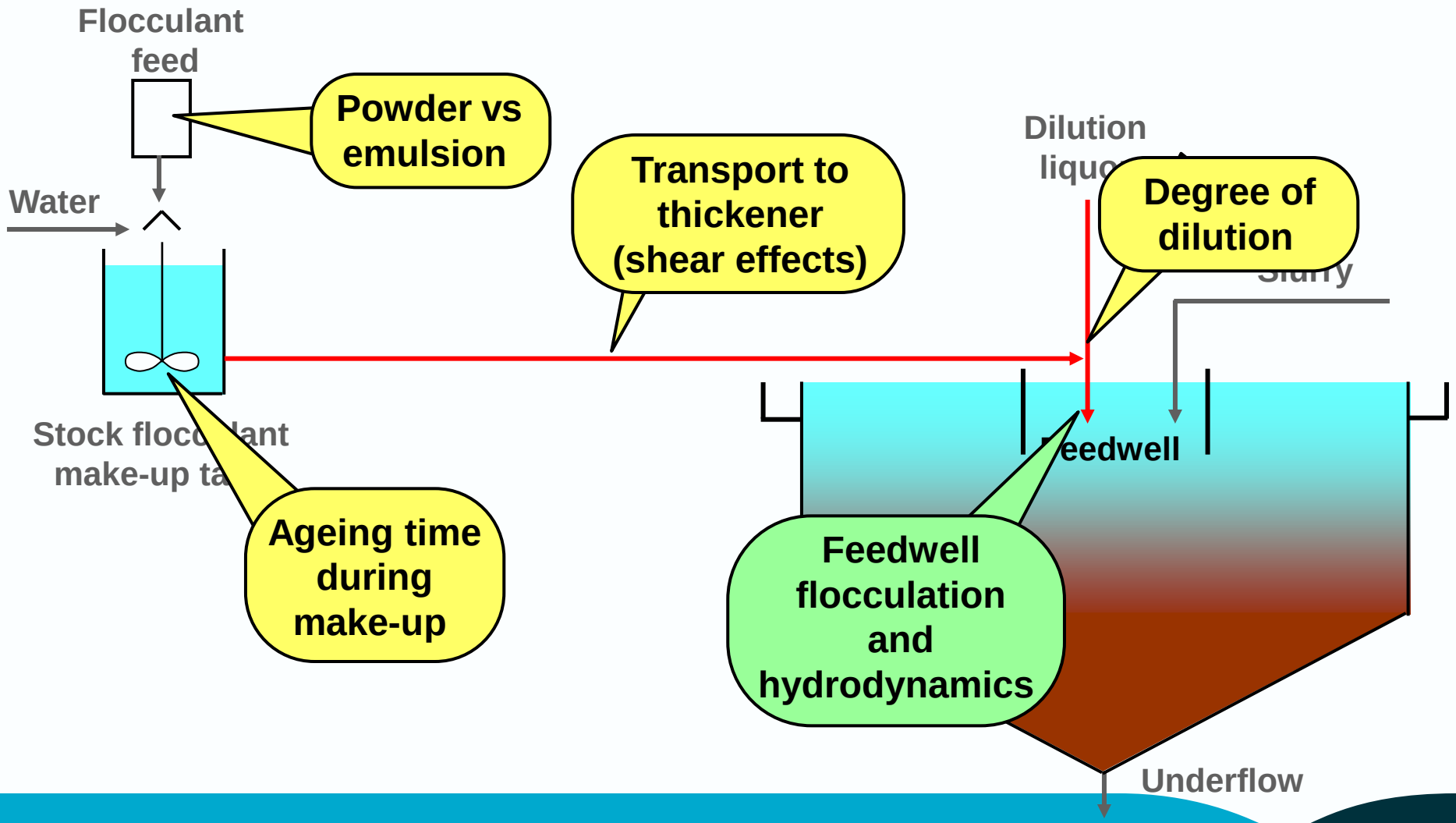


Flocculant selection and testing

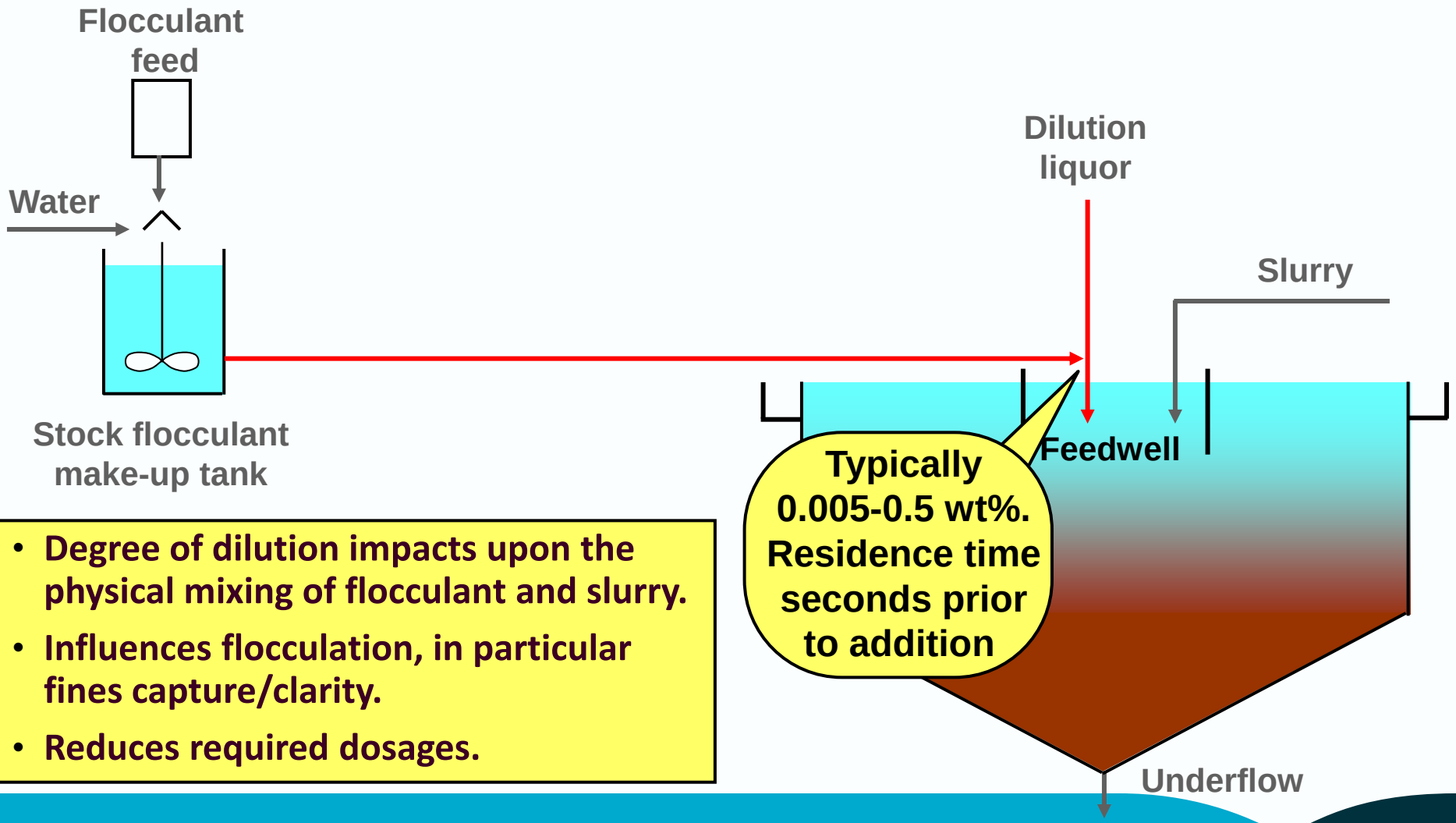
Thousands of papers dealing with the flocculation process and the effects of flocculants. *>90% are "very poor" to "#$&%".*

- Stirred beaker tests are largely irrelevant for feedwell flocculation.
- Flocculant comparisons at a single fixed dosage are confusing:
  - Full dosage curves required.
  - Lowest required mass dosage is not a performance measure.
- Flocculants should be well diluted:
  - Must separate physical mixing (viscosity) effects from "chemistry" effects.
  - Worry about the practical dosing issues afterwards.
- Flocculant comparisons at one solids loading are dangerous:
  - Optimum solids concentrations will exist.
  - May be different for different flocculants.
- Cylinder tests are done badly and don't give good control over mixing.

Flocculant use is complicated enough …

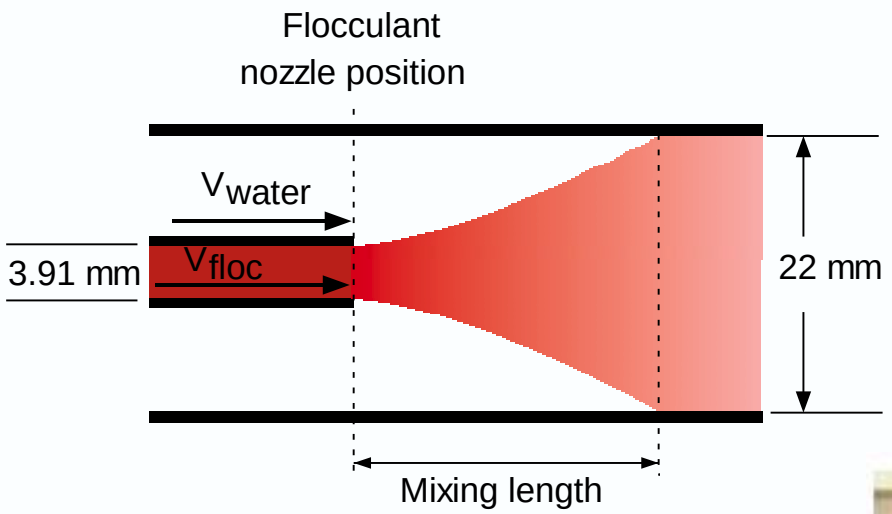


Dilution prior to dosing



- **Degree of dilution impacts upon the physical mixing of flocculant and slurry.**
- **Influences flocculation, in particular fines capture/clarity.**
- **Reduces required dosages.**

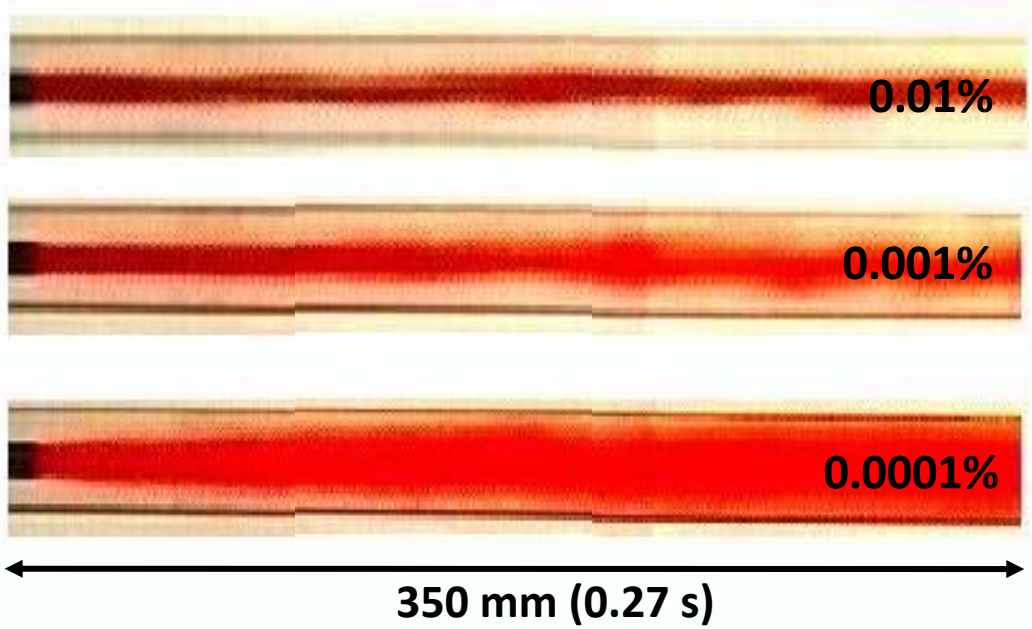
Flow visualisation (P266C)



Variables: water velocity, velocity ratio, flocculant concentration, flocculant molecular weight, flocculant type

V_w = 1.4 m/s (30 L/min)

V_{floc} = 1.67 m/s (1.2 L/min)



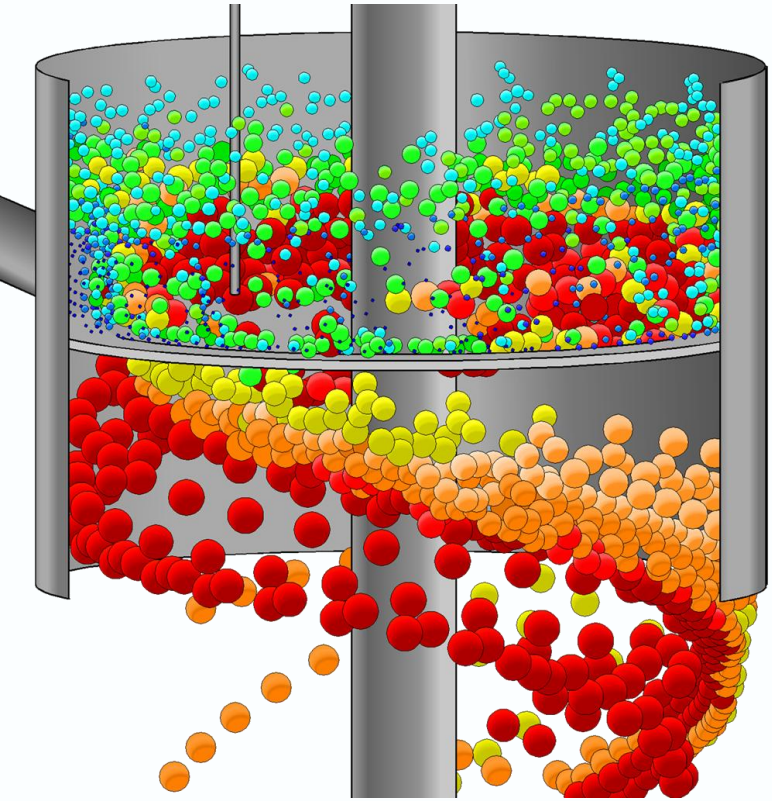
Flow visualisation (P266C)

The efficiency of flocculant distribution depends on:

- Relative flow velocities of the two streams - higher flocculant velocities give better mixing.
- Viscosity of flocculant solution:
  - lower concentrations mix more rapidly
  - lower molecular weight gives faster mixing
  - homopolymers mix more rapidly than copolymers

- **Larger volume of more dilute flocculant will mix more efficiently.**
- **Flocculant better added into dilution stream in feedwell (assuming it then meets the solids).**

That's fine qualitatively, but …

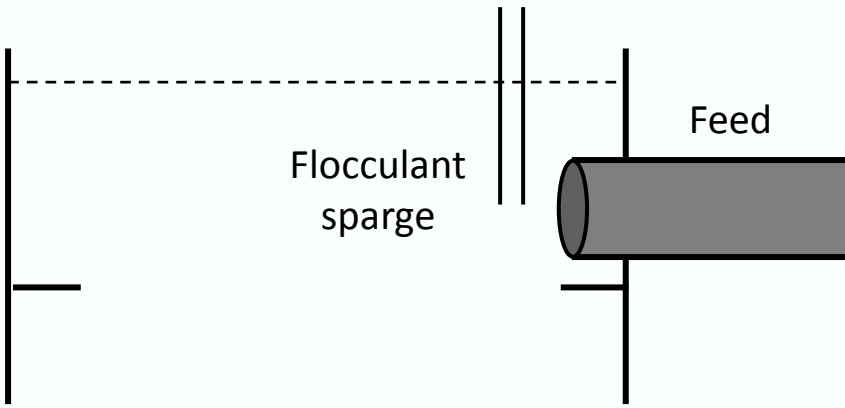


- AMIRA P266 has developed the world's most advanced computational fluid dynamics (CFD) model of feedwells.
- Flocculation effects predicted through:
  - Flocculant adsorption model (P266B).
  - Population balance (PB) model (P266E).
- PB-CFD is a unique tool to capture the effects of shear, residence time and solids concentration on extent and efficiency of flocculation.

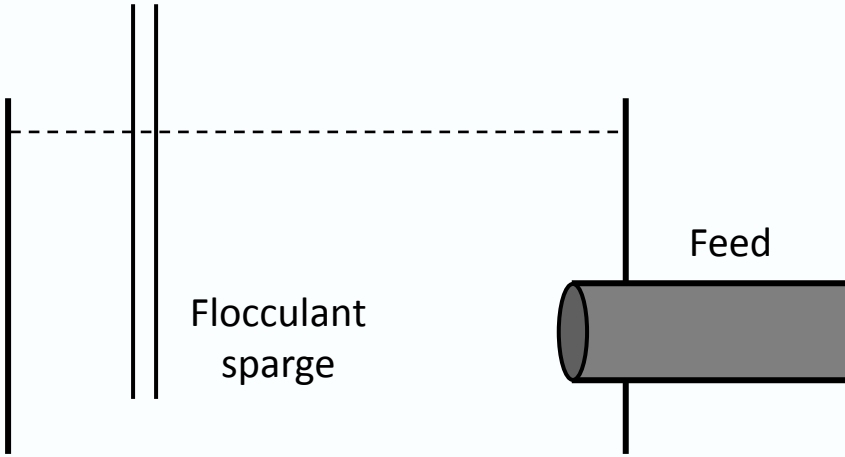
The impact of flocculant concentration/viscosity is not accounted for within feedwell PB-CFD

Potential impact on feedwell performance

- In a well operated, turbulent feedwell, with flocculant dosed appropriately, mixing through the solids may still effective.
- High flocculant concentrations may be an issue at lower shear.



- Some designs/operating conditions lead to poor contact or low residence times.
- Performance poor – higher dosages.
- Potential to discharge unadsorbed flocculant – detrimental to downstream processes.



Our approach

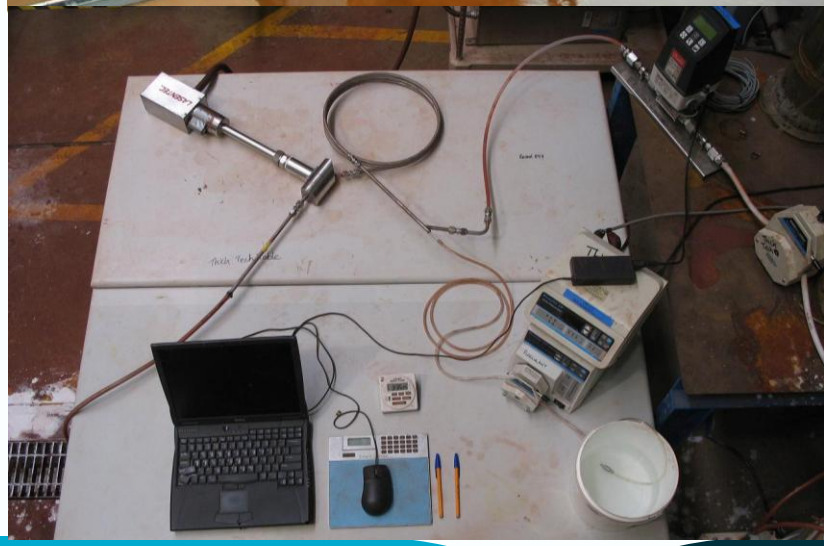
- Quantify the effect of flocculant concentration on the kinetics of aggregate growth and breakage.
- Obtain proper characterisation of flocculant viscosity:
  - What is the best technique for this?
  - Effect of concentration at both low and high ionic strength.
- Improve on flow visualisation as a guide to flocculant mixing in pipes:
  - Ultrasonic velocity profiling (UVP).
  - Electrical resistance tomography (ERT).
- Try to draw upon these results in CFD for:
  - Pipe flow.
  - Feedwell.

If we can't fully model it, can we at least correct for it?

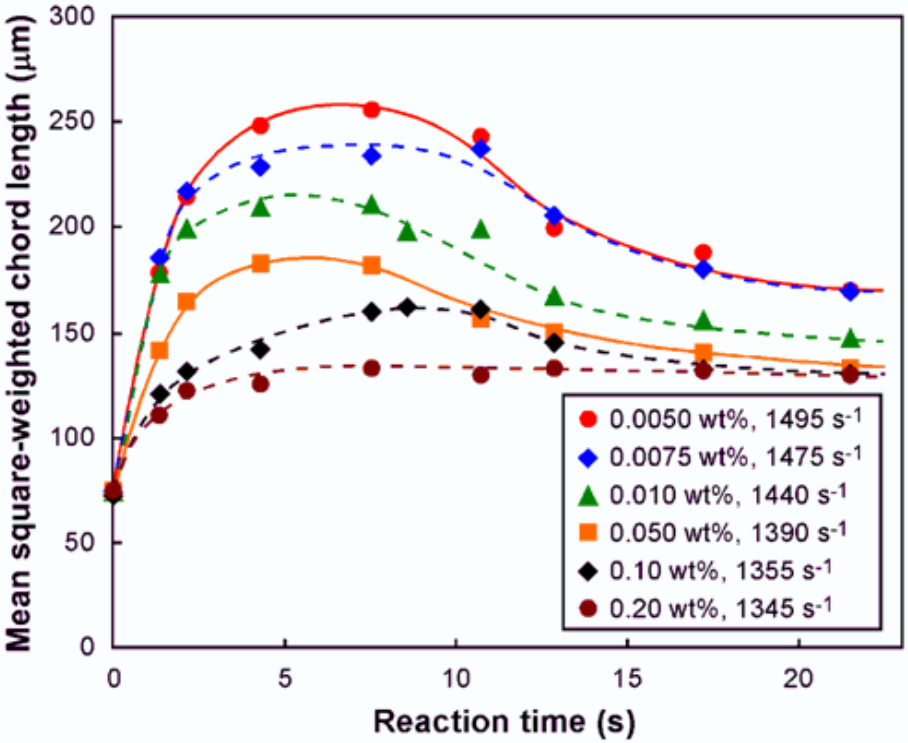
Quantification of flocculation kinetics

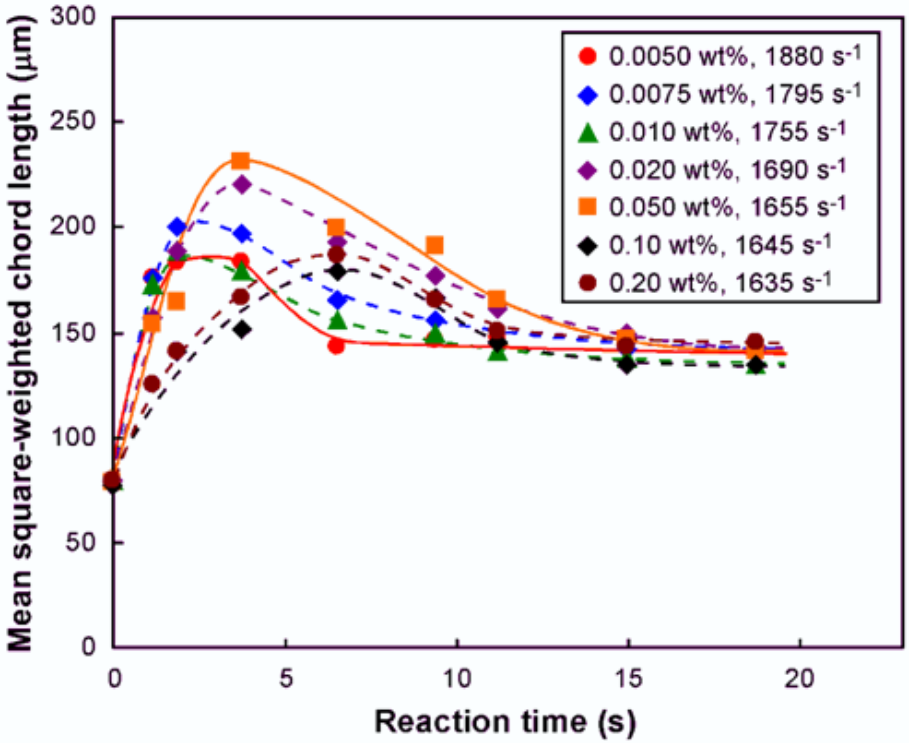
- Full-scale pipe reactor system:
  - Turbulent pipe flow (22 mm ID).
  - FBRM for real-time indication of size.
  - Mean shear rate and reaction time controlled.
  - Settling rates at matched reaction times.
  - PB parameter estimation across exp. matrix.
  - 4 fitted parameters and a fractal dimension.

- Small-scale pipe reactor system:
  - 8 mm ID coiled pipe.
  - Flow rates reduced tenfold.
  - Site-based work much easier.



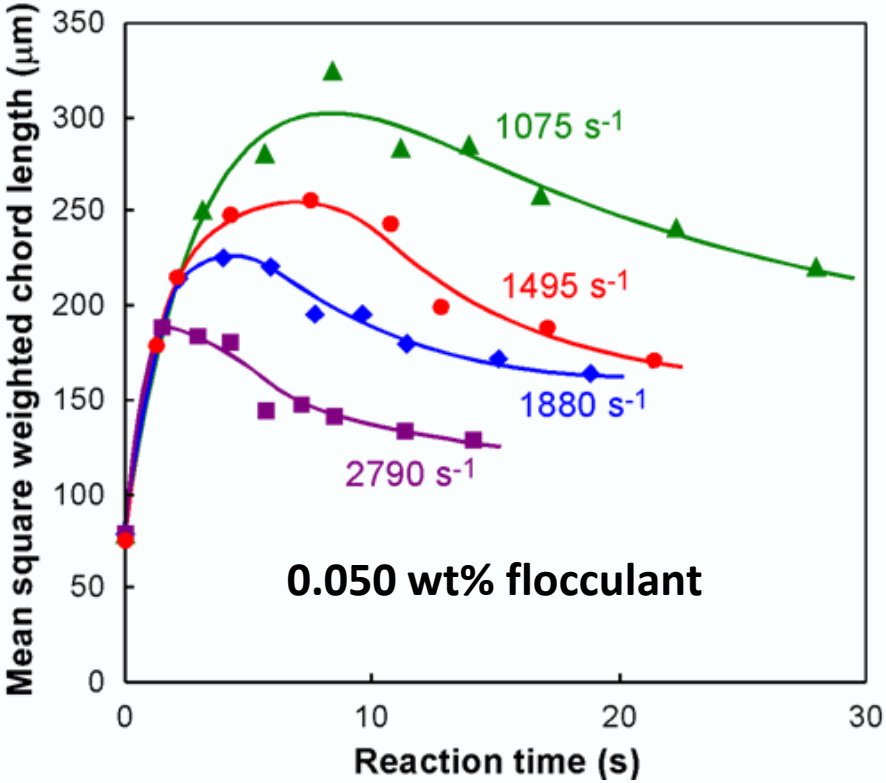
Impact of flocculant concentration

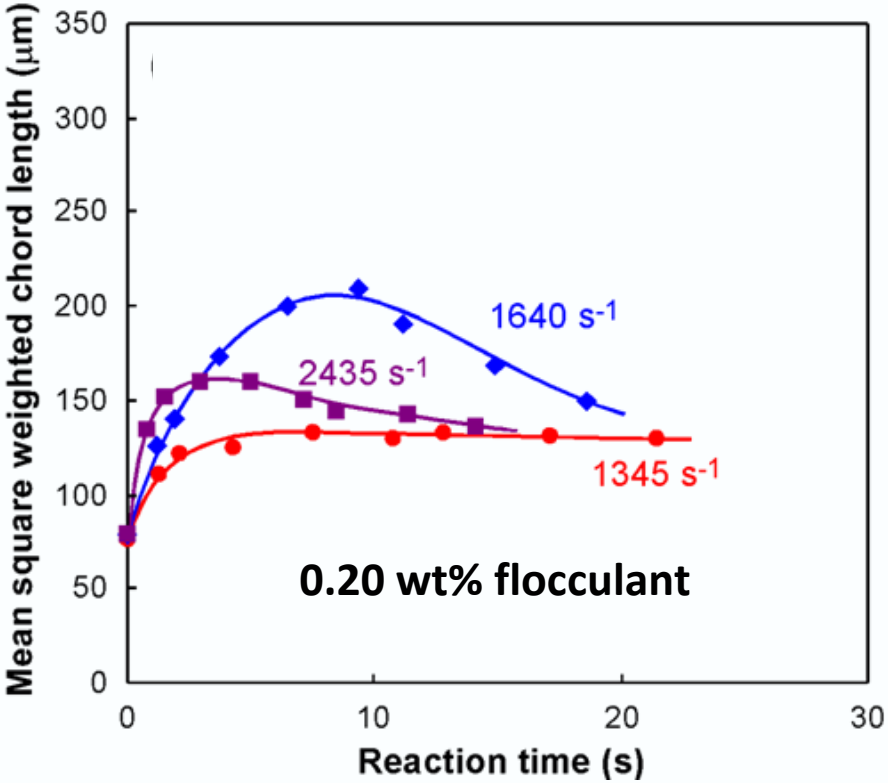




- **At a lower mean shear rate, highest dilution best.**
- **Under higher shear, an optimum dilution observed.**
- **Only minor mixing enhancement from the variations in flocculant stream velocity.**

Impact of mean shear rate



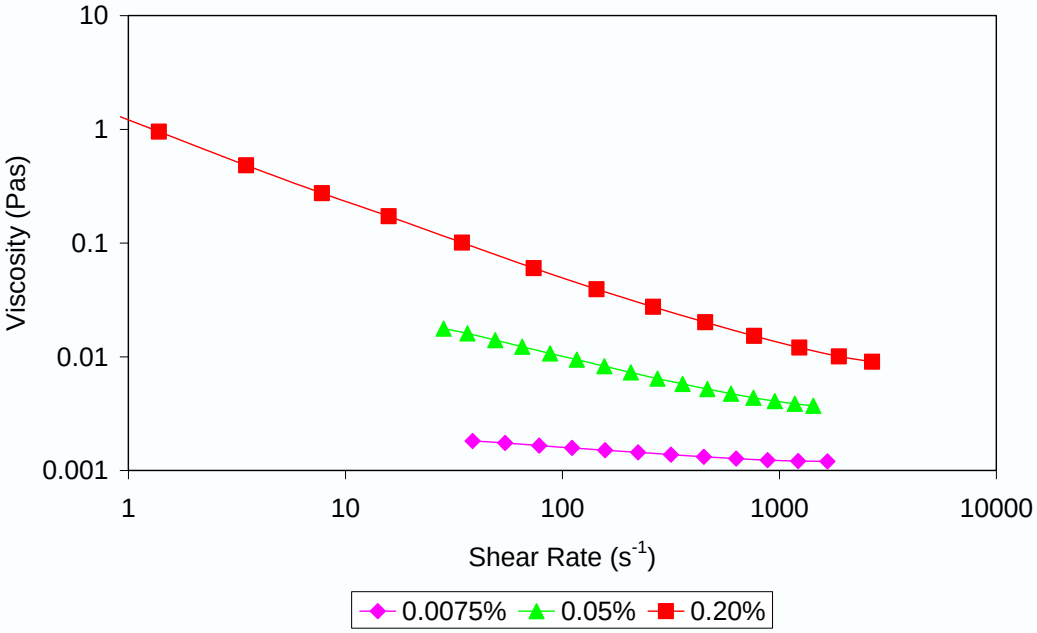


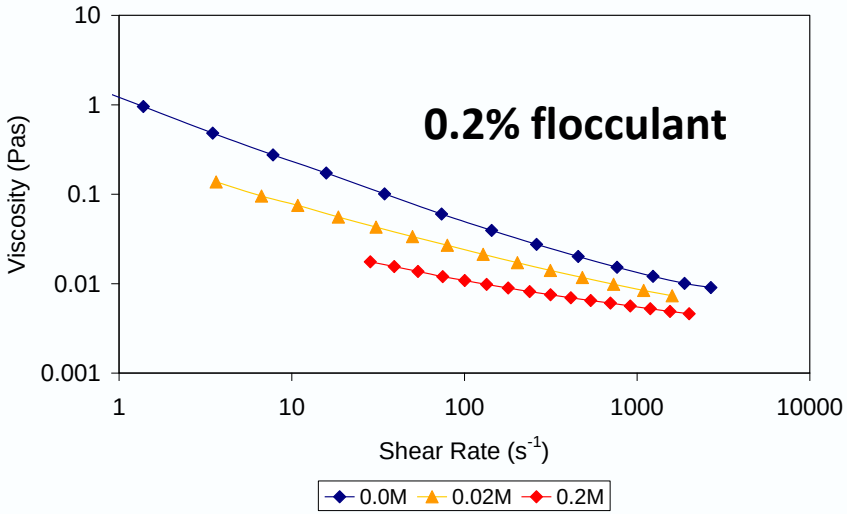
Decrease in aggregate size as mean shear rate increases is well captured by PB model

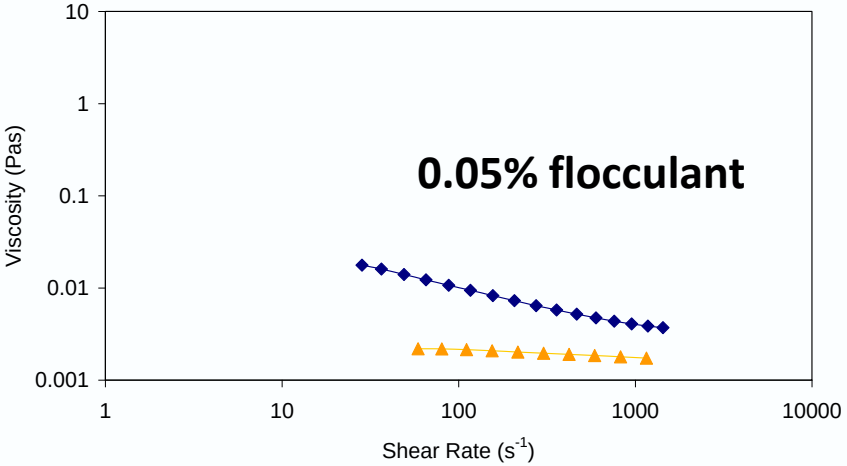
Observation of an optimum mean shear rate is NOT captured by PB model

Solution viscosity for 30% anionic flocculant

Bohlin rheometer
40 mm parallel plate geometry
Measurements all at 25°C





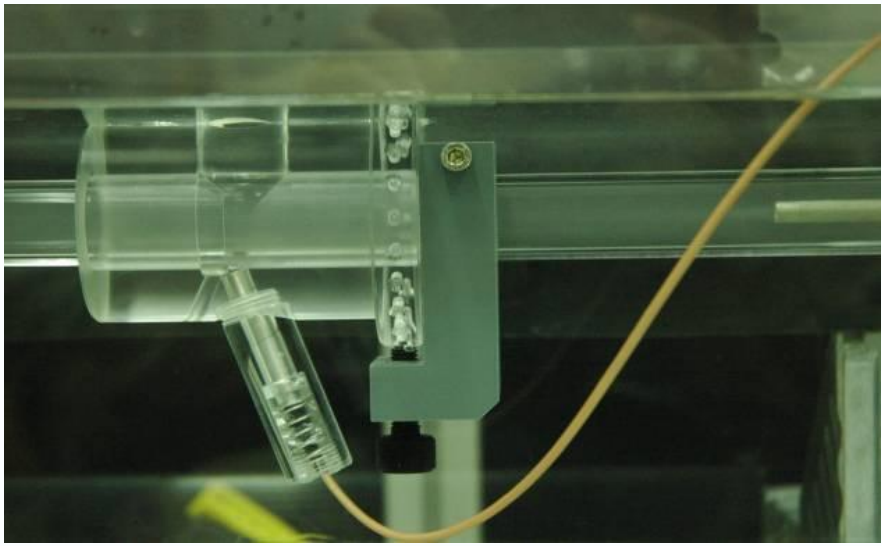


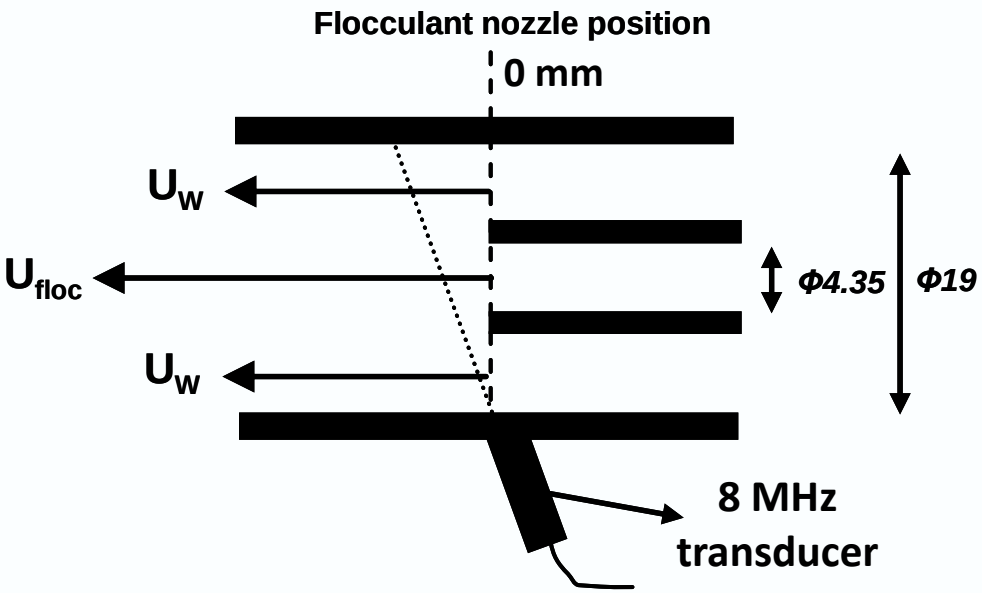
Implications

- The presence of salts shields repulsions from carboxylate groups in anionic flocculants and reduces coil dimensions.
- This affects flocculation in two ways:
  - Lower flocculant viscosity and potential for better mixing.
  - Changes in the aggregation process (reduced surface charge, but also reduced bridging potential).
- In terms of describing flocculant concentration effects:
  - Impact of rheology/concentration on mixing will be better dealt with through CFD, separate from the PB model itself.
  - Specific impact of salt on extent of aggregation can only be captured through separate PB parameter estimation.

Ultrasonic Velocity Profiling (UVP)

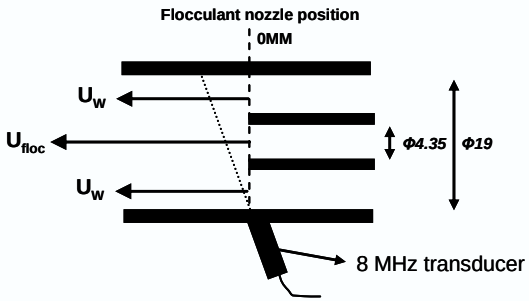
- Acoustic Doppler.
- Requires particulates in the fluid.
- Minimal intrusion.
- Velocity profile along beam (up to 3 m).
- Sampling rates up to 100 Hz.
- Speed ranges:
  - Low 0.09 m s^{-1}.
  - High 10 m s^{-1}.

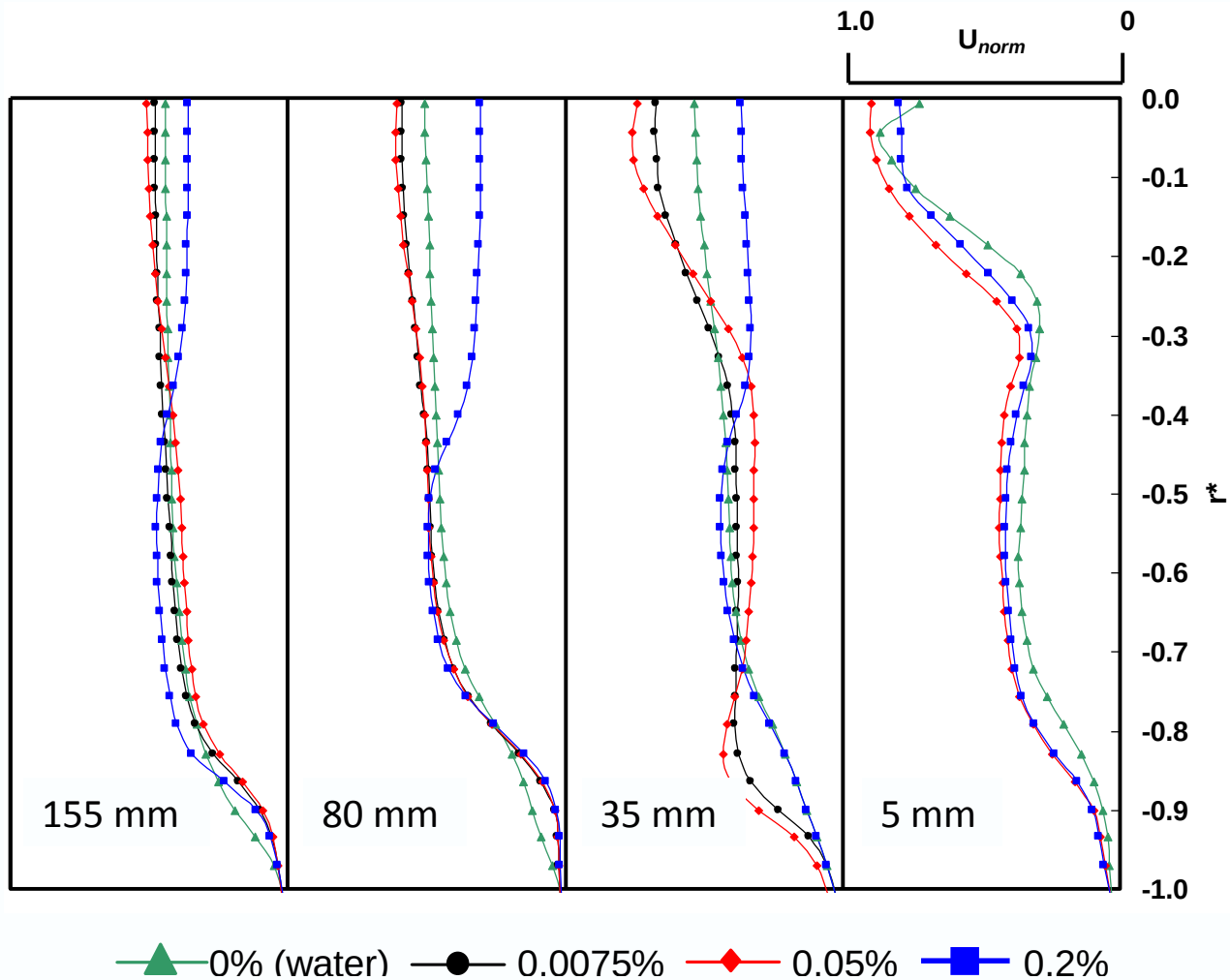




Velocity profiles for flocculant addition

- $U_{floc} > U_w$
- No salt addition

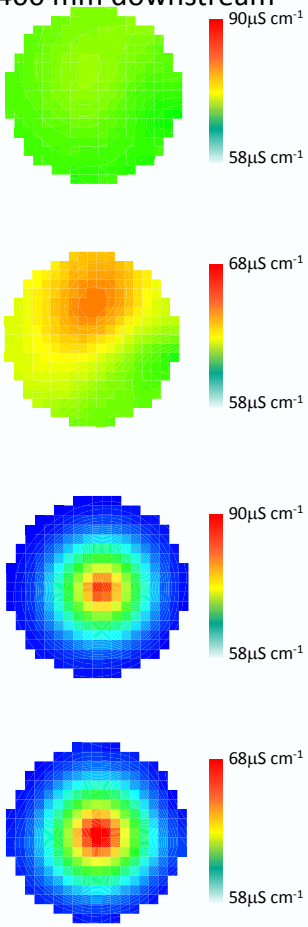




Flow visualisation and ERT

High flocculant concentration (0.2%-powder) not mixing under flow conditions.

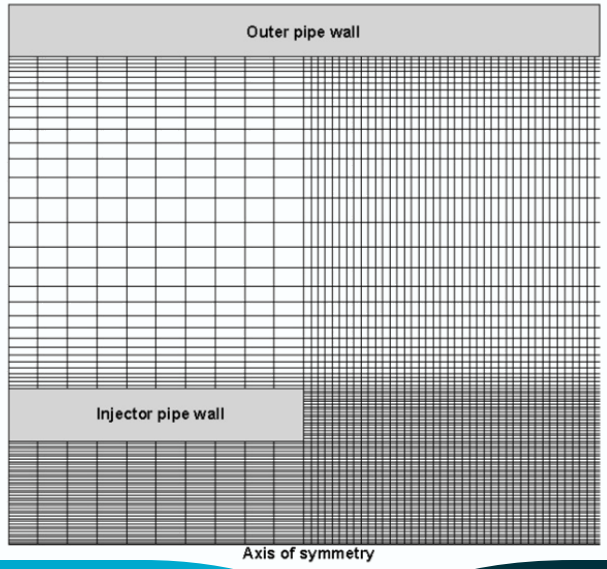
ERT measurement at 400 mm downstream



CFD approach to flocculant mixing

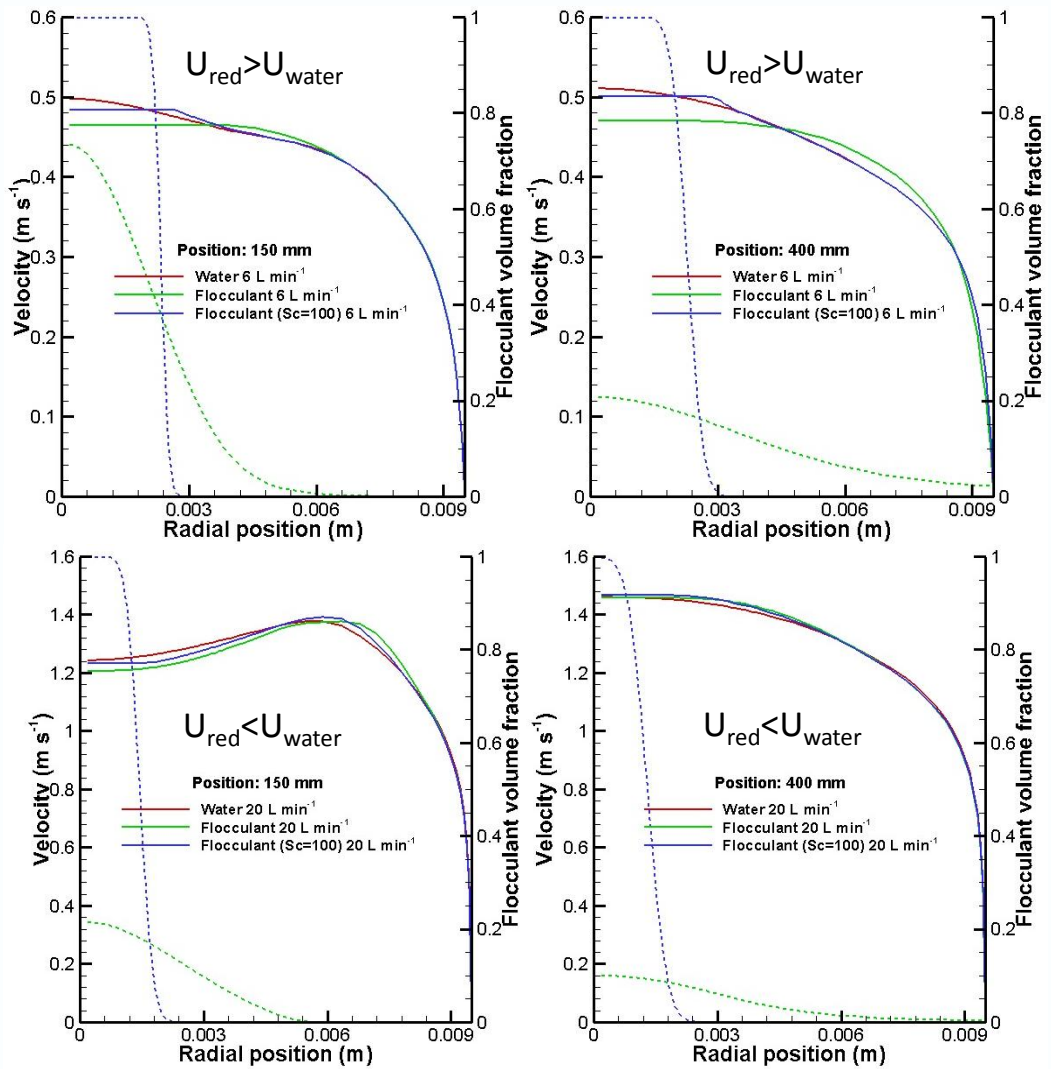
- Velocity profile tends toward fully developed conditions:
  - Suggest that momentum diffuses unhindered in spite of the lack of mixing.
  - Calculated mass flow based on velocity does not match expected values.
- CFD simulations of pipe mixing:
  - Conducted with homogeneous mixture model.
  - Diffusion of flocculant controlled via the scalar transport equation and the Schmidt number:

$$\mathrm{Sc} \equiv \frac{\mu}{\rho \mathrm{D}} = \frac{\text{momentum diffusion}}{\text{mass diffusion}}$$



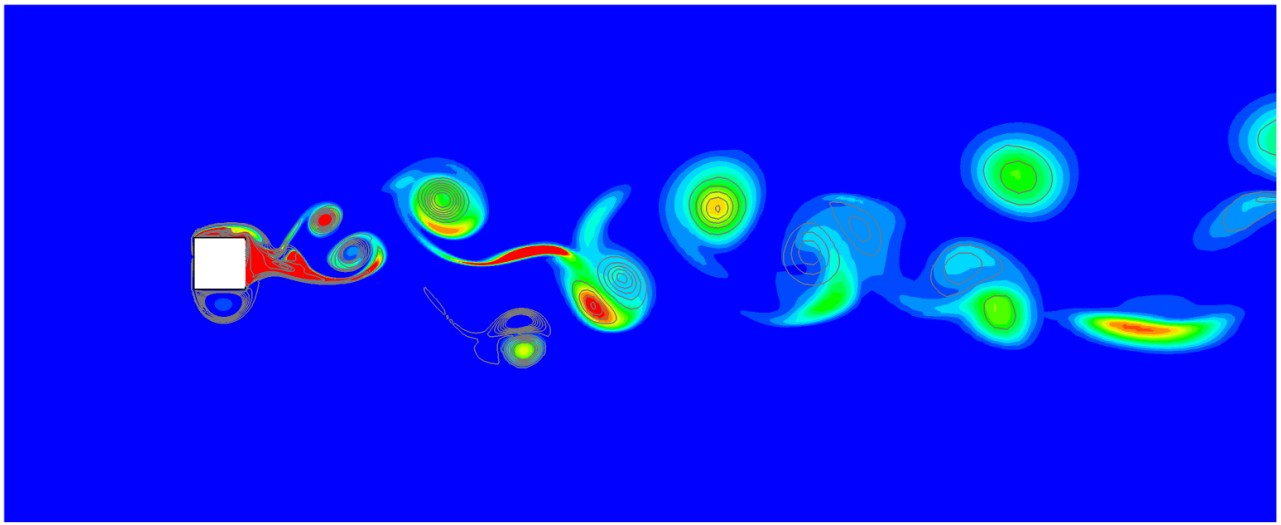
CFD approach to flocculant mixing

- Schmidt number has a small to negligible impact on velocity, depending on the flow conditions.
- Schmidt number has a large impact on flocculant diffusion:
  - For Sc=0.9, flocculant is nearly dispersed by the end of the pipe section.
  - For Sc=100, flocculant exhibits no practical mixing (some mixing from artificial numerical diffusion).



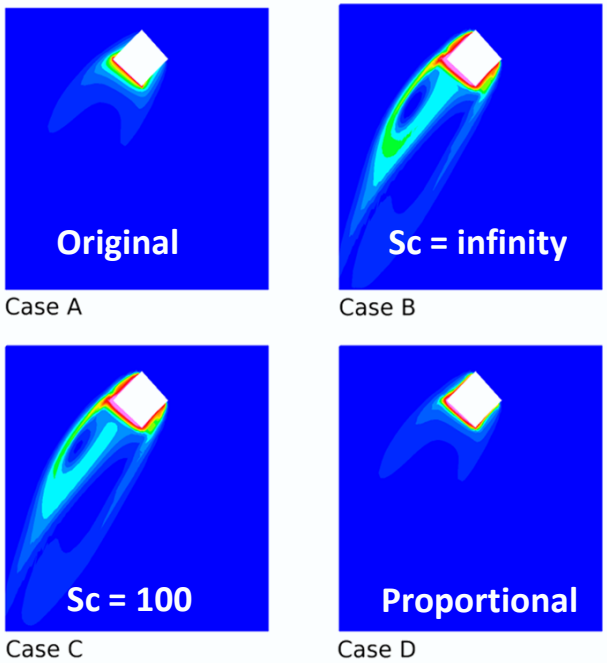
Extending to feedwell CFD

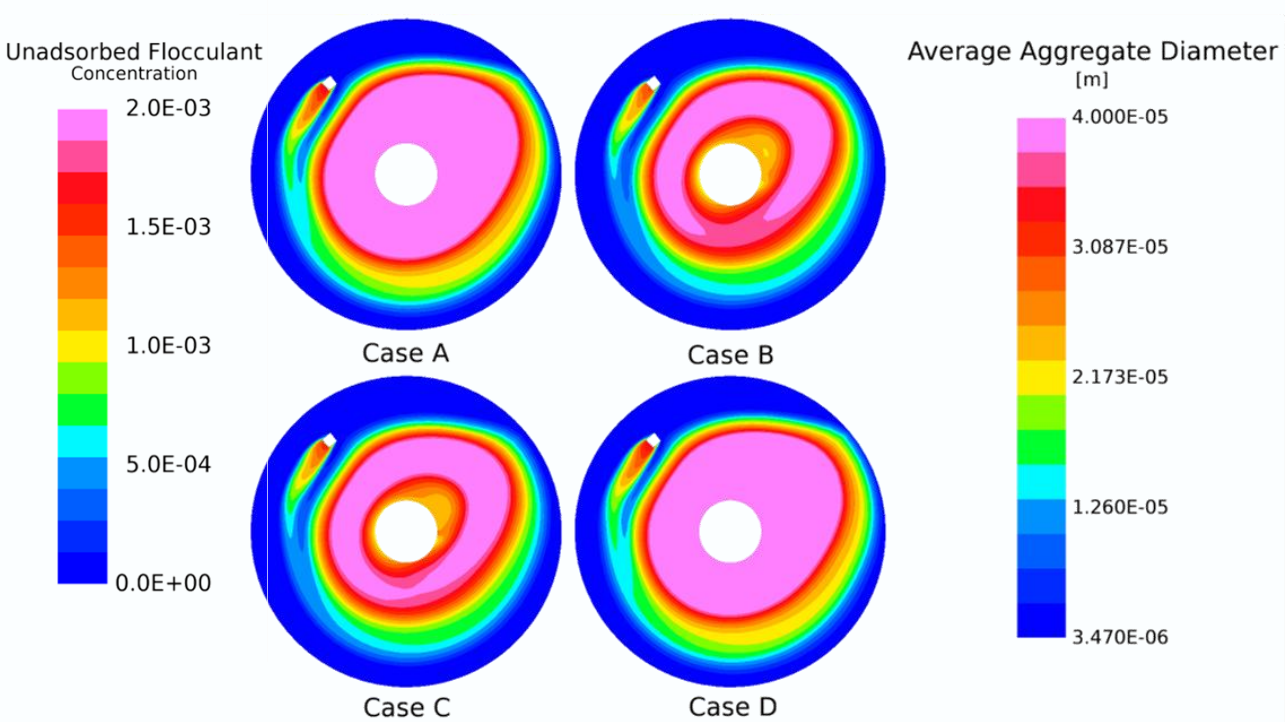
- Potential for large scale flow structures to break-up the flocculant phase.
- A 2D laminar simulation of a square sparge (100 mm wide) was runin a uniform flow field (1 m s^{-1}).
- Flocculant is not allowed to mix, but large scale vortices break it up nonetheless.



Extending to feedwell CFD

- Population balance results computed using QMOM.
- Computed aggregate diameter decreased by 30% due to poorer mixing in case B and C.





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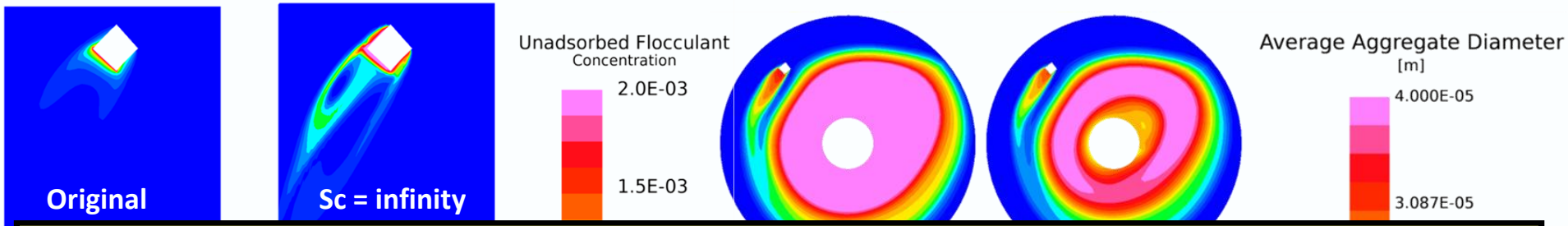

- **Small-scale eddies are the principal mechanism for homogeneous mixing of flocculant.**
- **Large-scale eddies can break-up flocculant into coarse packets.**
- **Turbulence naturally transfers energy from large-scale structures down to the smallest-scale.**
- **This process is hindered by the flocculant viscoelasticity.**

Summary

- Velocity profile is a poor indicator of mixing.
- Concentrated flocculant exhibits poor mixing which can be approximated by a high Schmidt number.
- Numerical model requires additional work to capture both concentrated and dilute mixing behaviour.
- Large flow structures in a feedwell can breakup flocculant stream.
- Homogeneity of the mixing cannot be determined at present.
- Numerical models incorporating polymer behaviour may help understand and capture mixing dynamics at smaller length scale.

Thank you. Questions?

AMIRA P266G "Improving Thickener Technology"

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