Optimising the flocculation of clay-based tailings from mineral processing

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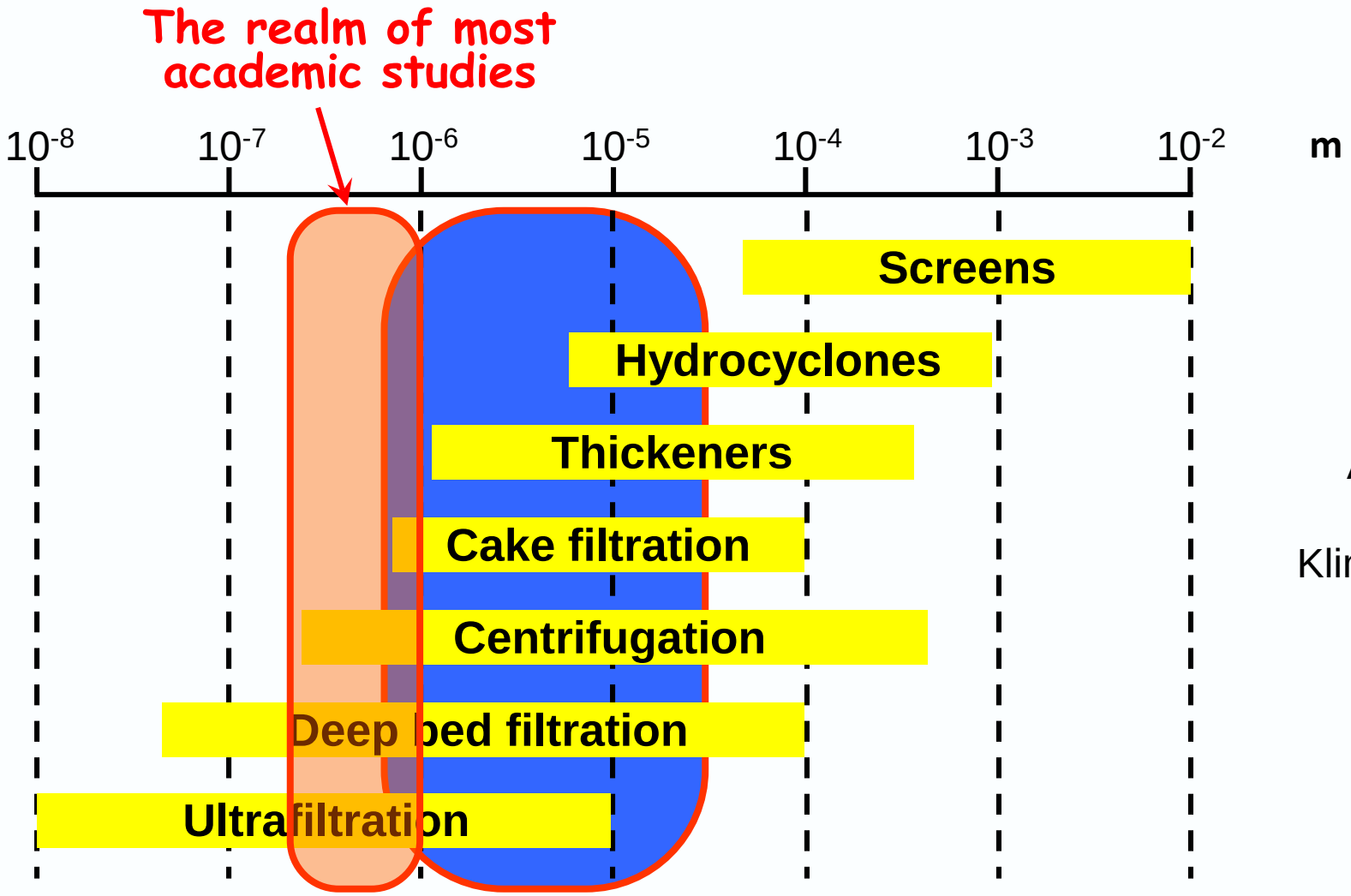
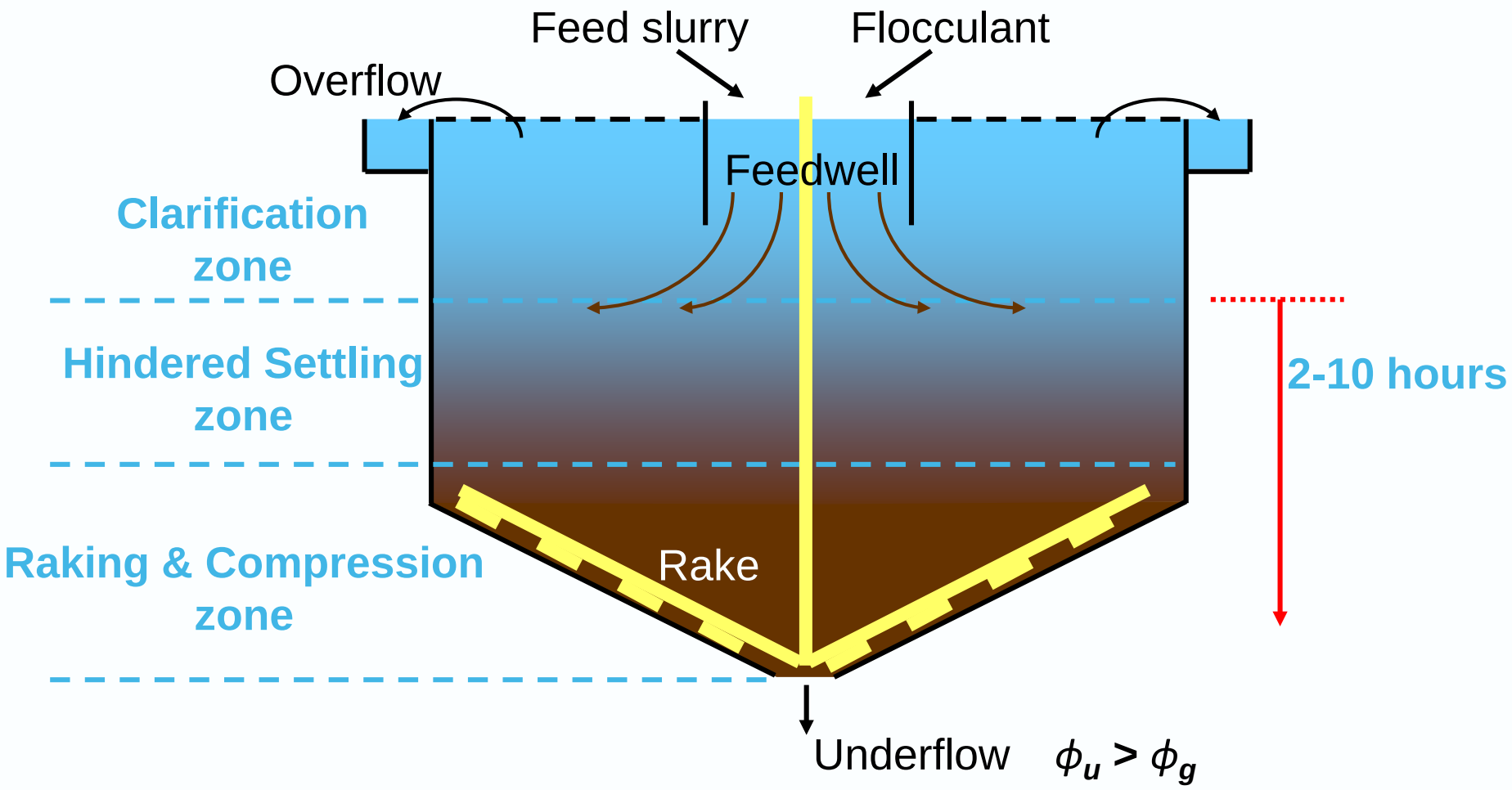
Particle sizes for solid-liquid separation



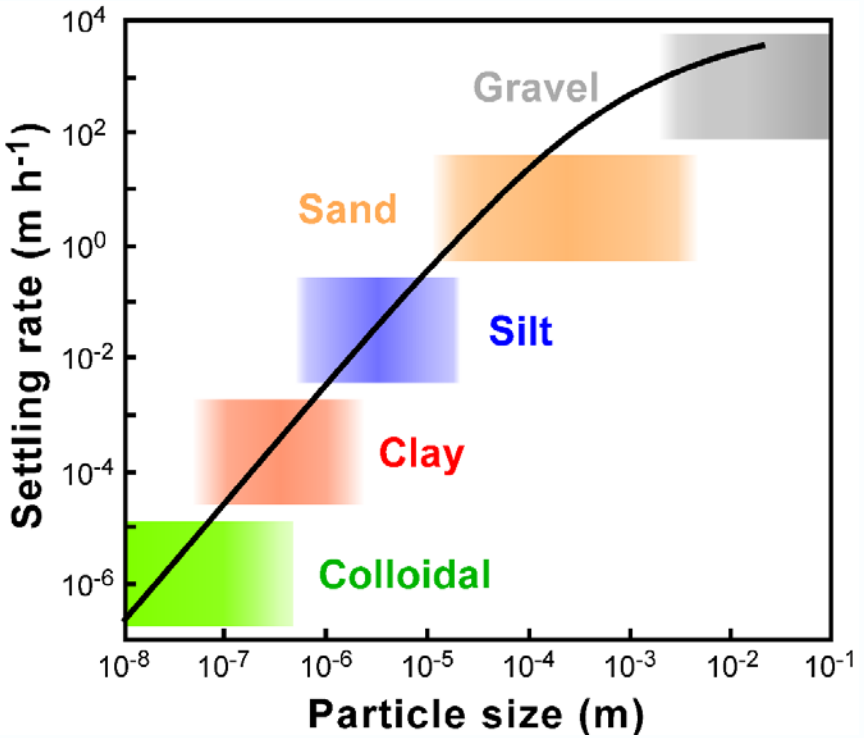
Adapted from Klimpel (1998)

Gravity thickening



Why we need to flocculate

- Typical thickener liquor rise rates ~2-5 m h^{-1}:
  - Clarifiers may be lower.
  - Modern thickeners much higher.
- Particles d_{50} 2-10 µm settle <1 m h^{-1}.
- Higher settling rates:
  - Allow faster feed flow (throughput).
  - Smaller thickeners (reduced capital).
  - Reduced residence time (reduces risk of precipitation/scaling).



Thickeners come in all shapes and sizes

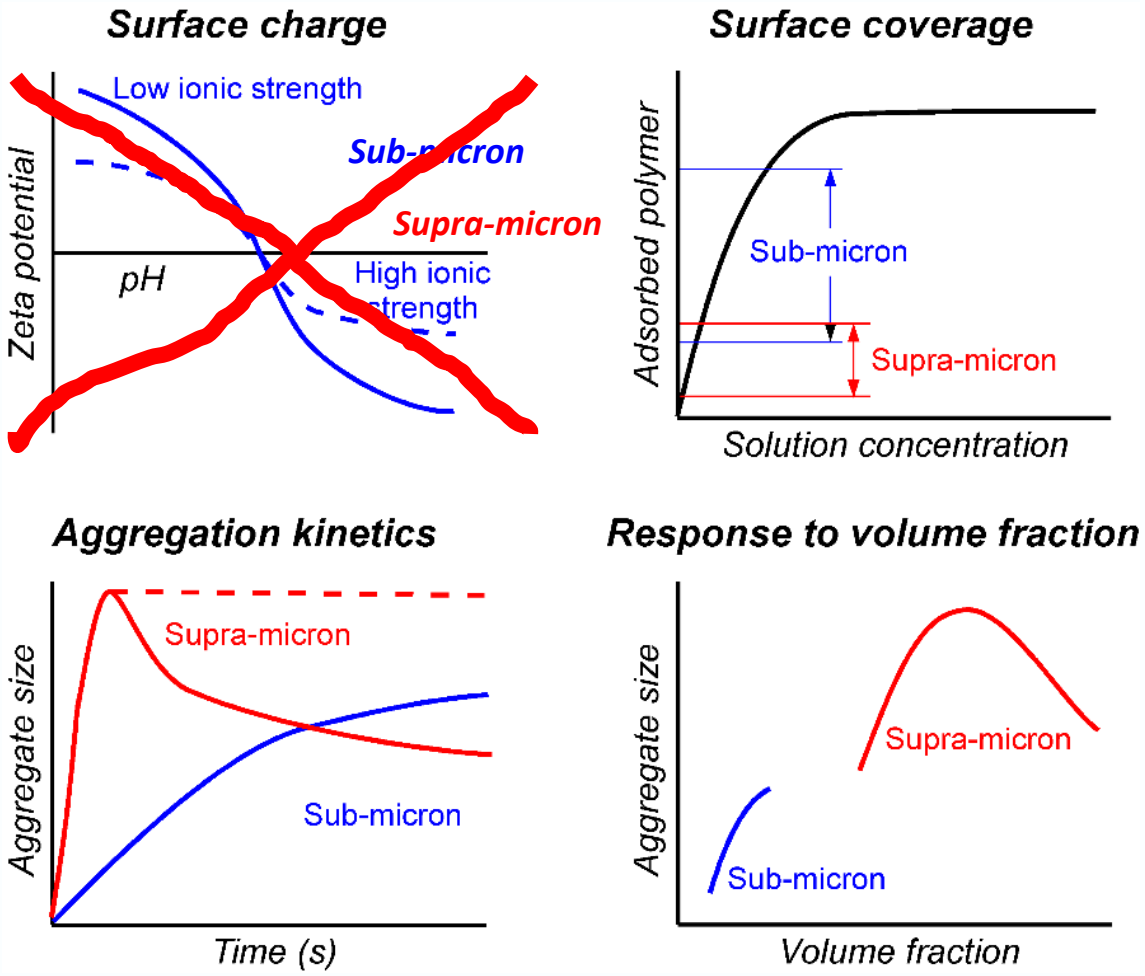
- All the above had problems with the way flocculation was being achieved.
- Need a clear indication of driver for change (throughput, clarity, feed change).
- Only the two on the right had such drivers.
- All had clays, but only top right had problems due to clays.

In my humble opinion …

- The literature overflows with papers on flocculation:
  - Most of these cite theories/papers that were done in the 1960s.
  - Classical studies of “flocculation” (especially on clays) focused very much on low solids water treatment.
  - Even the most advanced recent studies tend to look at sub-micron standard particles (e.g. latexes).
- Some good, some bad, but much of it is of questionable relevance to flocculation in mineral processing.

Dangerous to assume concepts that apply to sub-micron colloids or wastewater/sludge clarification will automatically extend to mineral systems

The impact of particle size

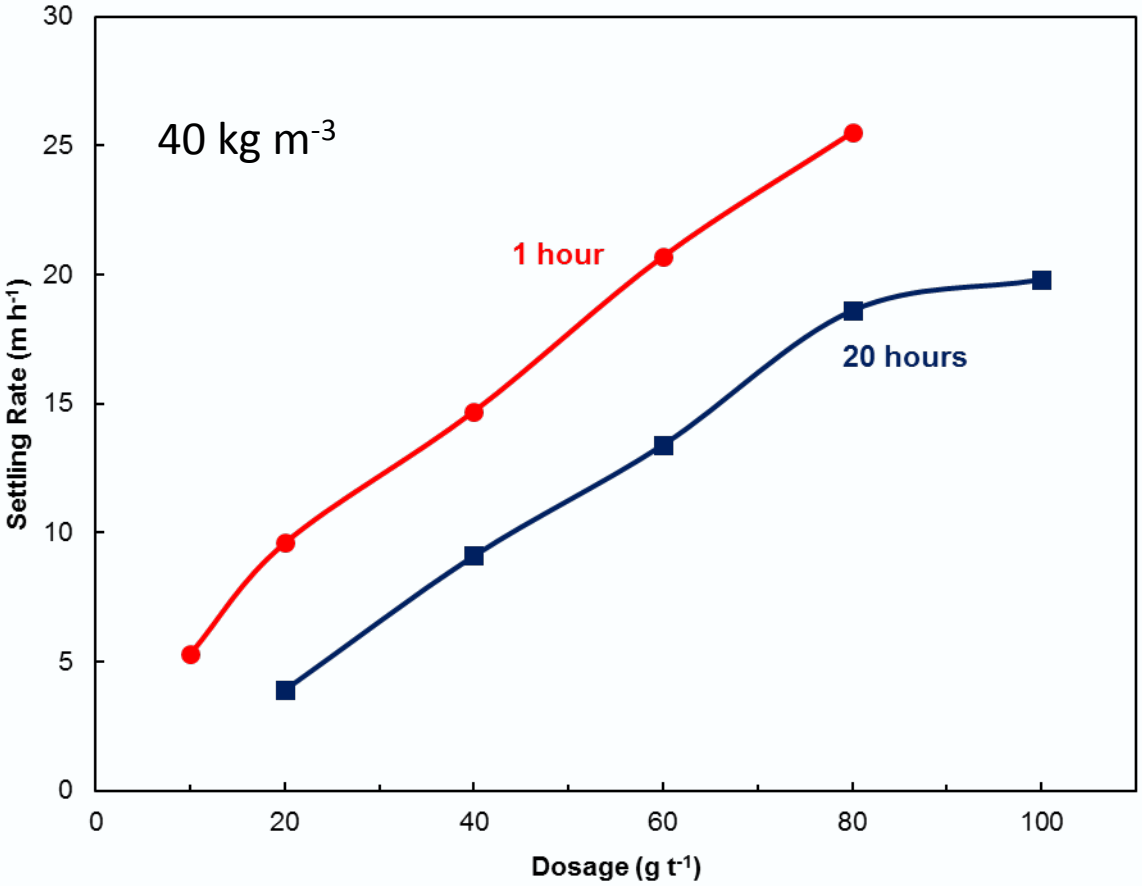


Clays in mineral processing can span both domains

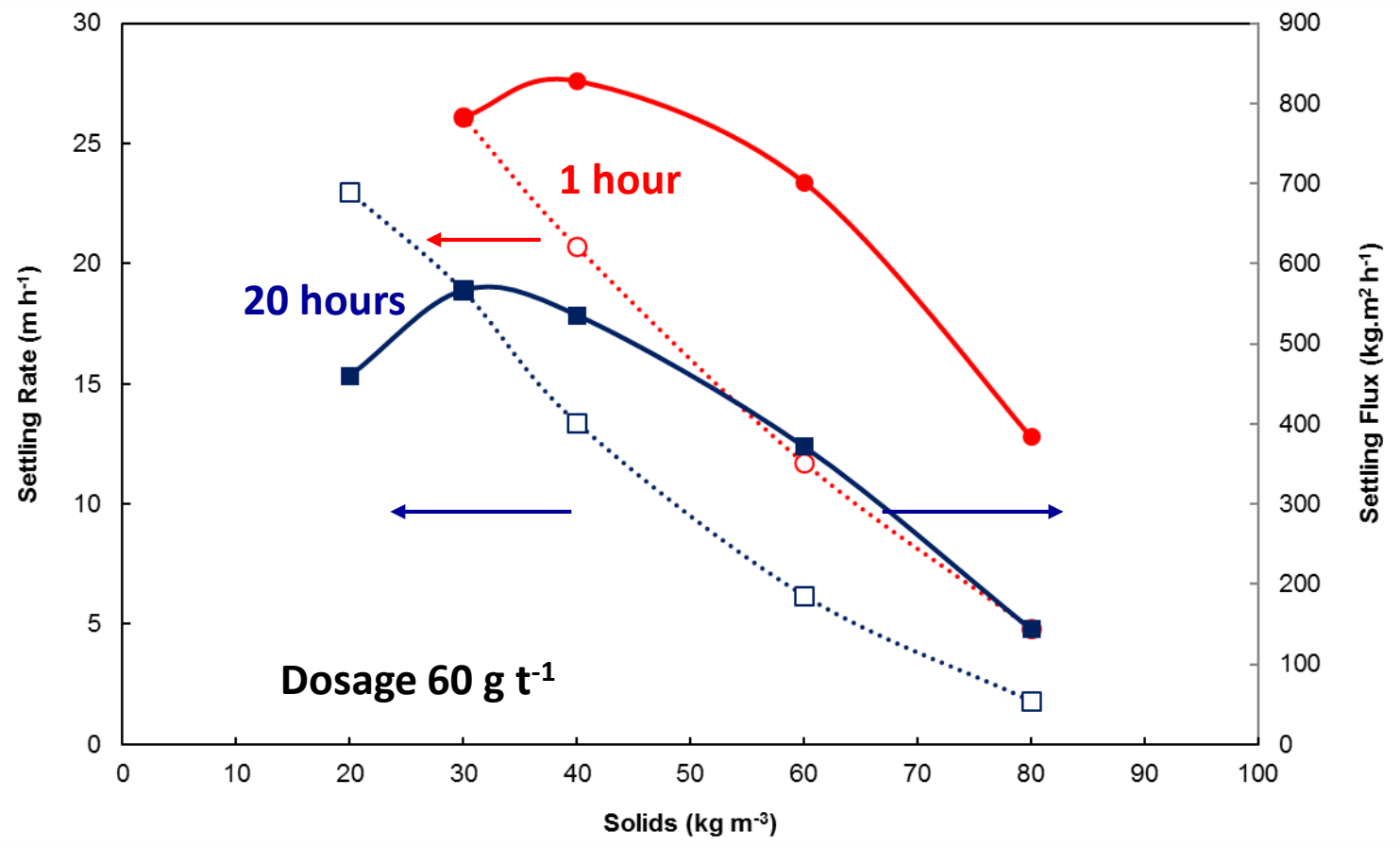
The problem with particle size distributions (PSDs)

- Malvern PSDs and sieve results allow comparisons to be made on a mass or volume basis.
- Broad PSDs and variable coarse fractions make such comparisons problematic.
- For flocculation, particle number is much more important than particle volume.
- Malvern PSDs offer some sensitivity to particle number for systems with narrow distributions, but not always for “real” feeds.
- To demonstrate this:
  - Synthetic tailings 25% quartz (all solids -45 µm removed) and 75% clay.
  - Clay was a 4:1 mixture of kaolin and bentonite.
  - Made up at a total solids of 360 kg m^{-3} in 0.03 M $CaCl_2$.
  - Slurry known to release addition fines with stirring (800 rpm, 4 L baffled tank).

Dosage response after sampling and dilution

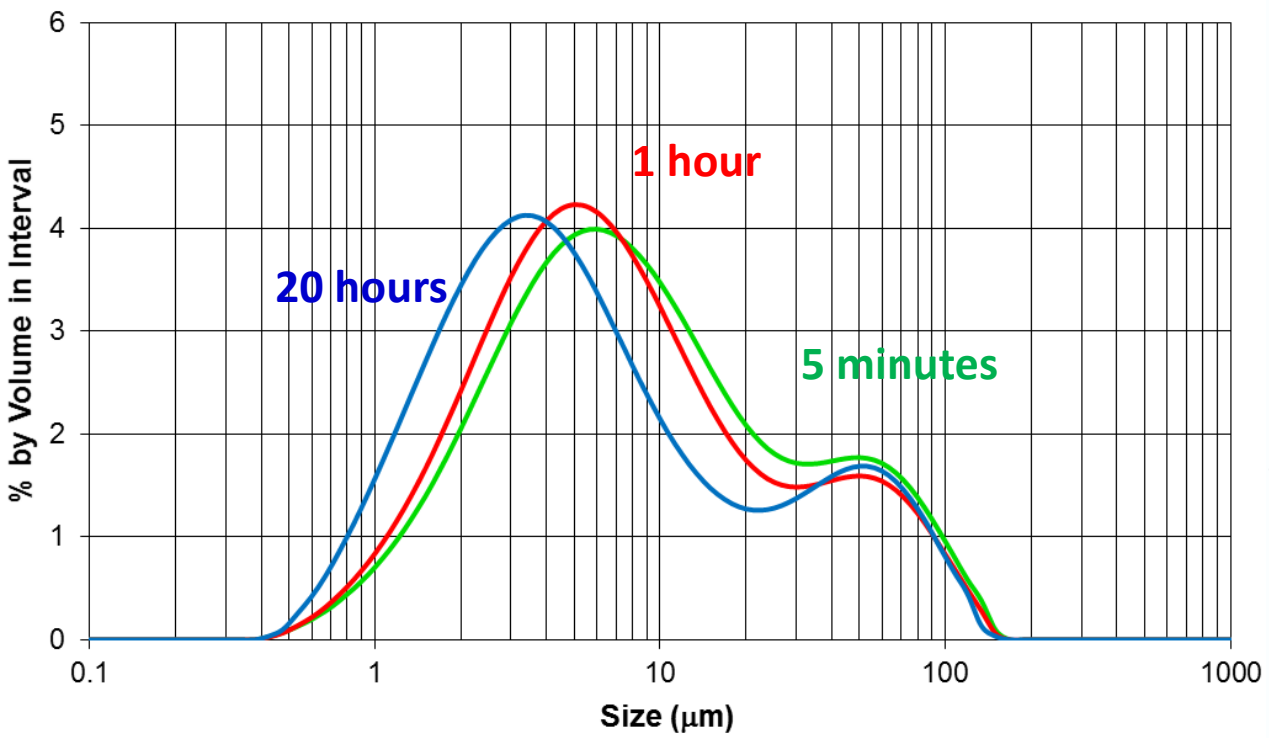


Solids response (fixed dosage)



- **If you don't understand or have control of the feed PSD in small-scale tests, there's less chance of getting reliable/useful results.**
- **Fully understanding a system requires knowledge of the solids response.**

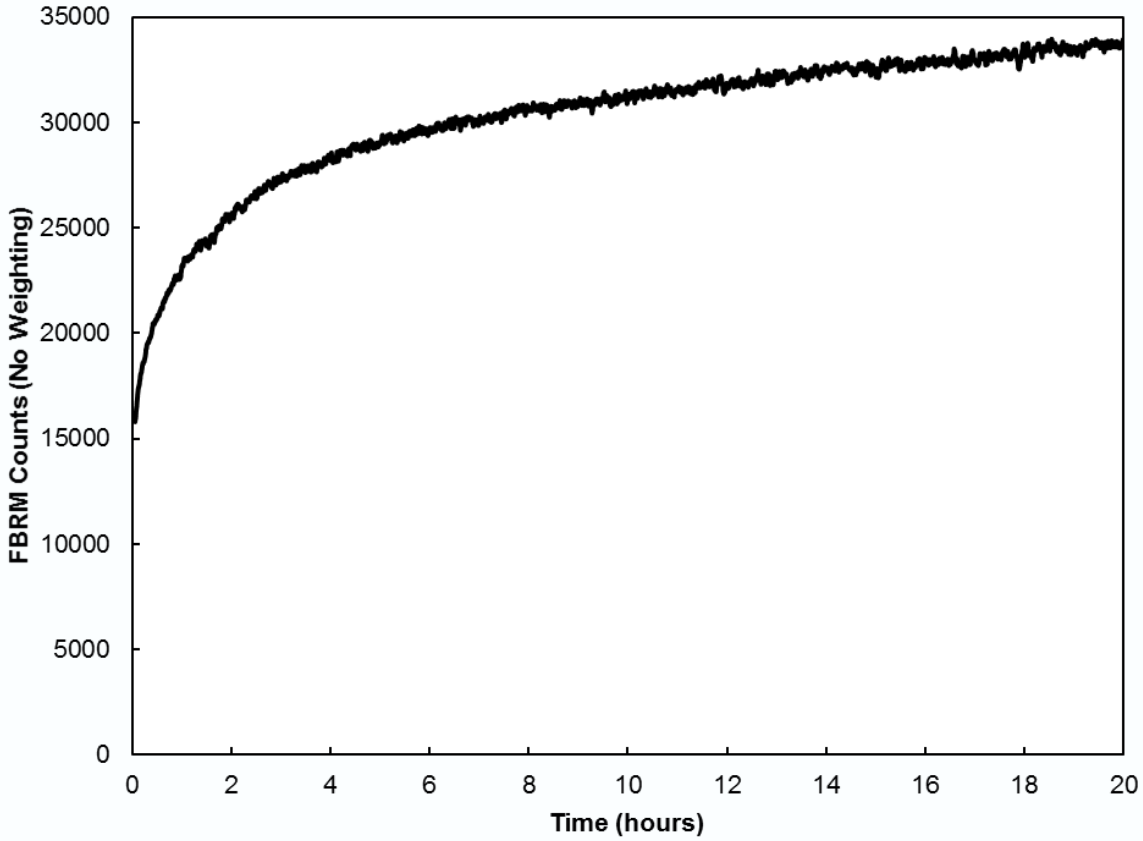
Malvern MasterSizer PSDs (no dispersant added, no sonication)



Vol%	5 min	1 h	20 h
<1 µm	3.0%	3.5%	6.6%
<5 µm	39.2%	44.5%	55.2%
<10 µm	61.7%	66.6%	71.3%

- <1 µm fraction offers sensitivity, but an unreliable statistic.
- Malvern PSDs measured at high dilution, rarely controlled, so no actual indication of concentration, esp. when coarse fraction is variable.

Focused beam reflectance measurement (FBRM)



- G400 FBRM released 2012 with better sensitivity to particle concentration.
- Use volume-weightings to examine aggregates, but now focus on raw counts – coarse particles make a negligible contribution.
- 45% increase in counts from 1 to 20 hours.
- Real-time, no dilution.
- Provides a good indication of fines contribution, even when fraction and size of coarse solids varies.

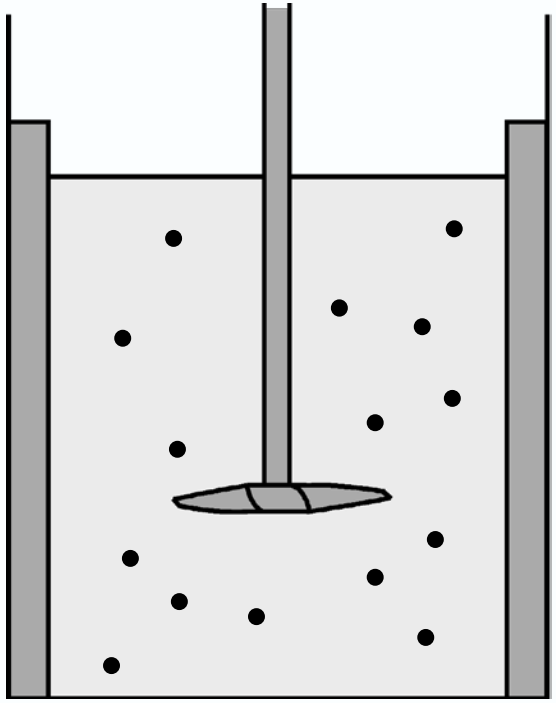
But FBRM is number-sensitive, not a number-counter!

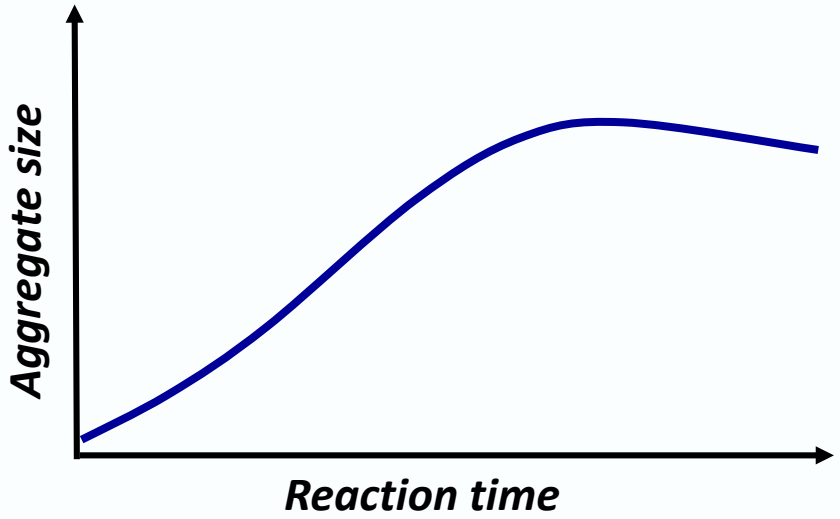
Seeking better number counts

- Many options, but want something robust, simple and with minimal dilution required.
- Canty TRUFLOW™ particle sizer.
- Image capture and analysis down to 0.7 µm in suspension:
  - Counts
  - Size
  - Shape
- Due to be set-up in our labs late June 2017.

Excess/poorly-defined mixing during flocculation

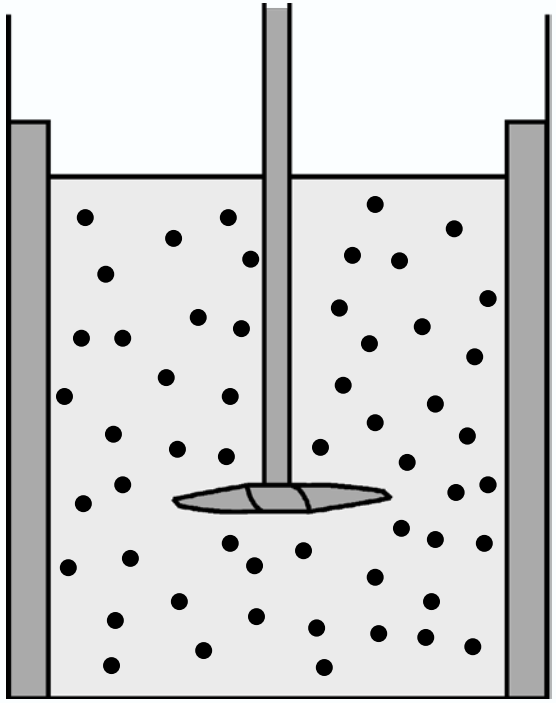
- "Jar tests" (stirred beakers/tanks) are commonly used for flocculation/coagulation tests in low solids water treatment.
- Low solids = low collision rates = long reaction times (minutes).

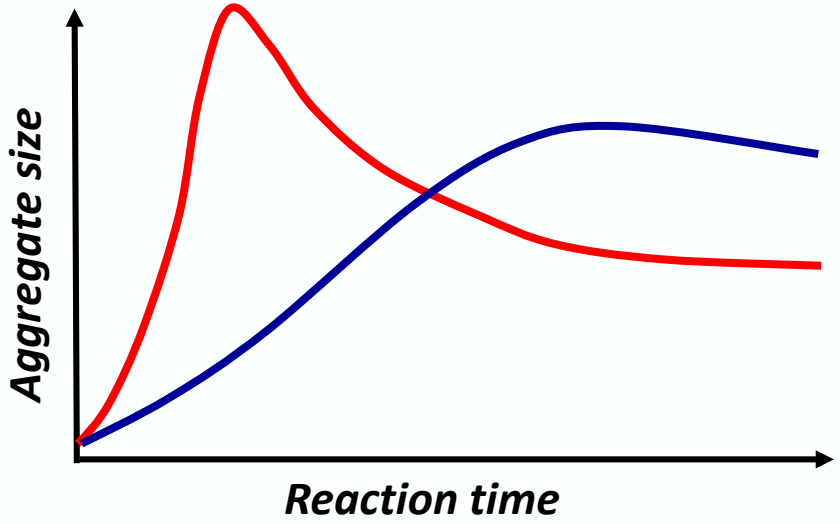




Excess/poorly-defined mixing during flocculation

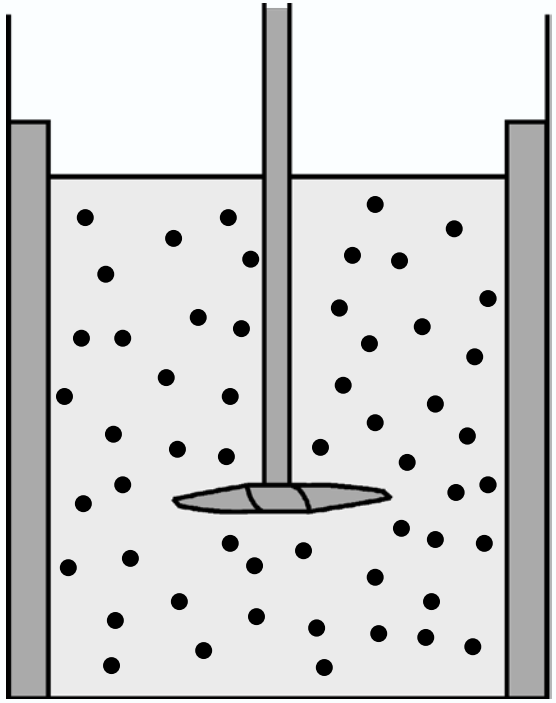
- Higher solids = higher collision rates = shorter reaction times.
- Also leads to a greater impact of breakage, which for bridging flocculation is mostly irreversible.

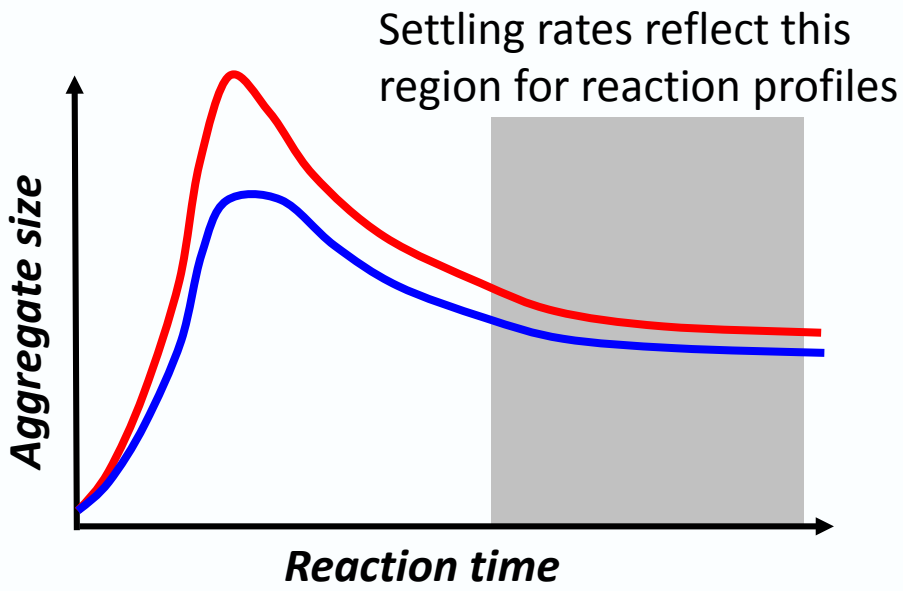




Excess/poorly-defined mixing during flocculation

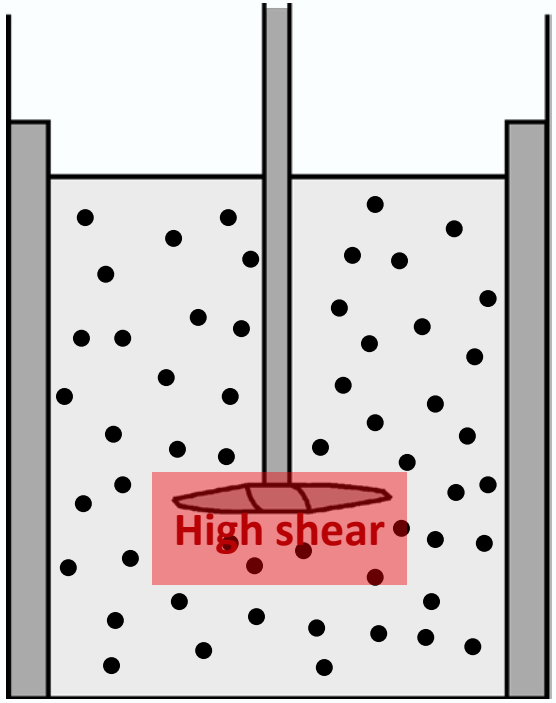
- Numerous published studies that first flocculate in stirred tanks, then transfer contents to cylinders to measure settling rates.
- Excess shear reduces sensitivity to product differences.

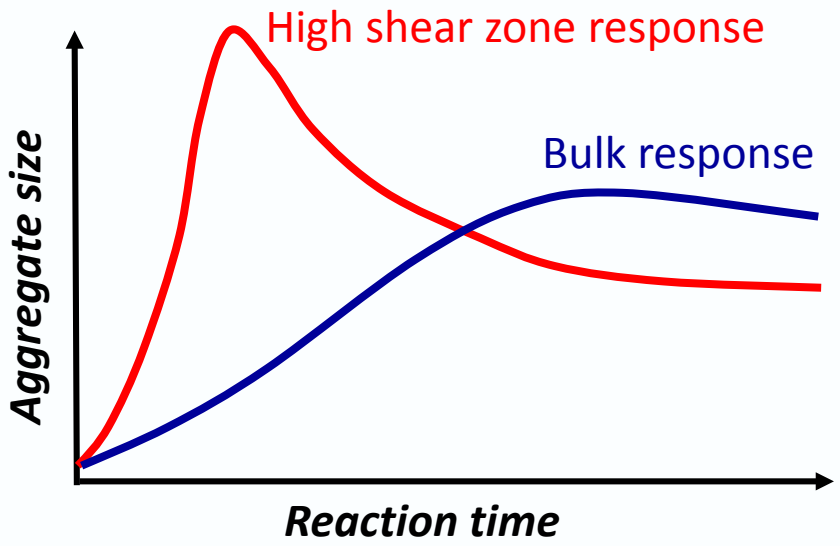




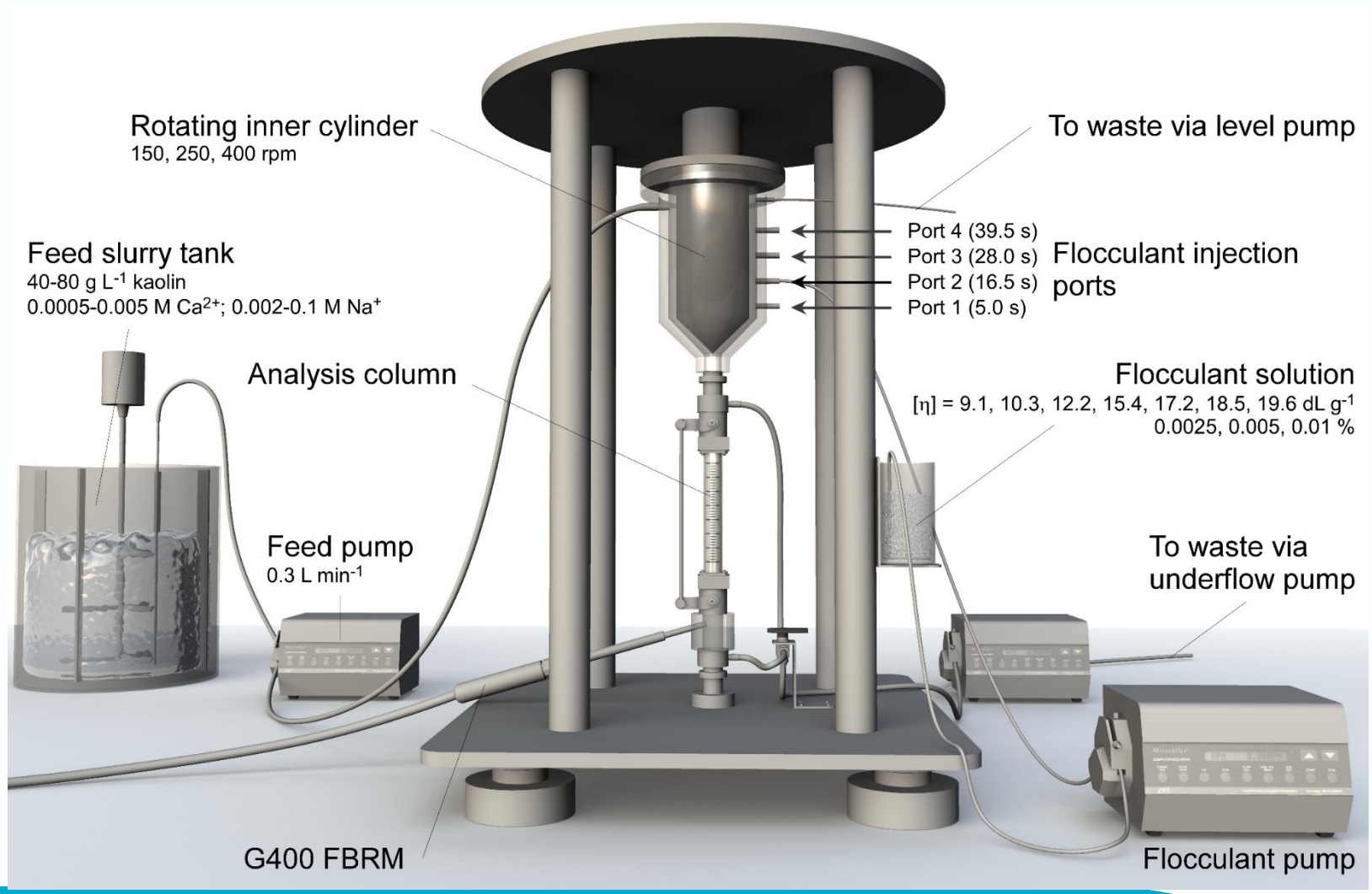
Excess/poorly-defined mixing during flocculation

- Reproducible mixing in cylinder tests is a high priority.
- Stirred tanks mixing reproducible, but broad range of shear rates.
- Flocculation will occur in all shear rate regions.



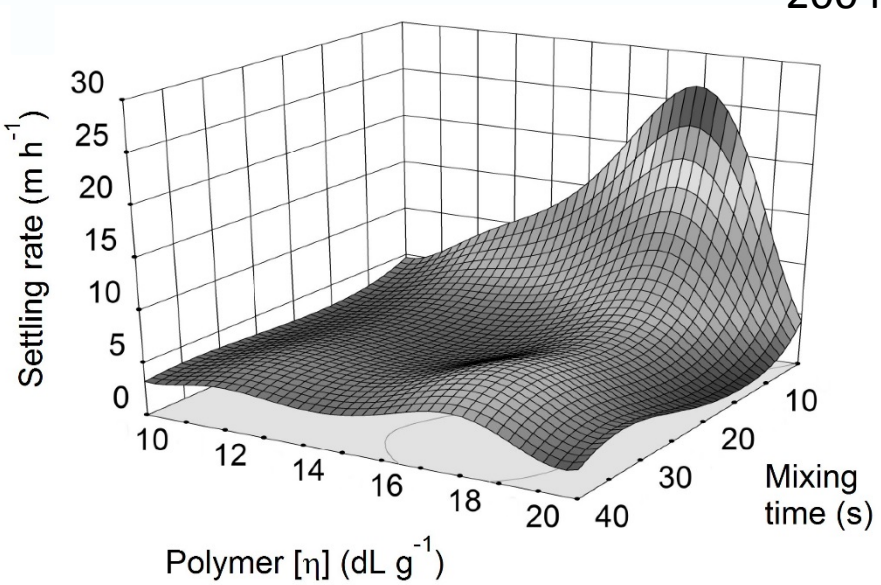


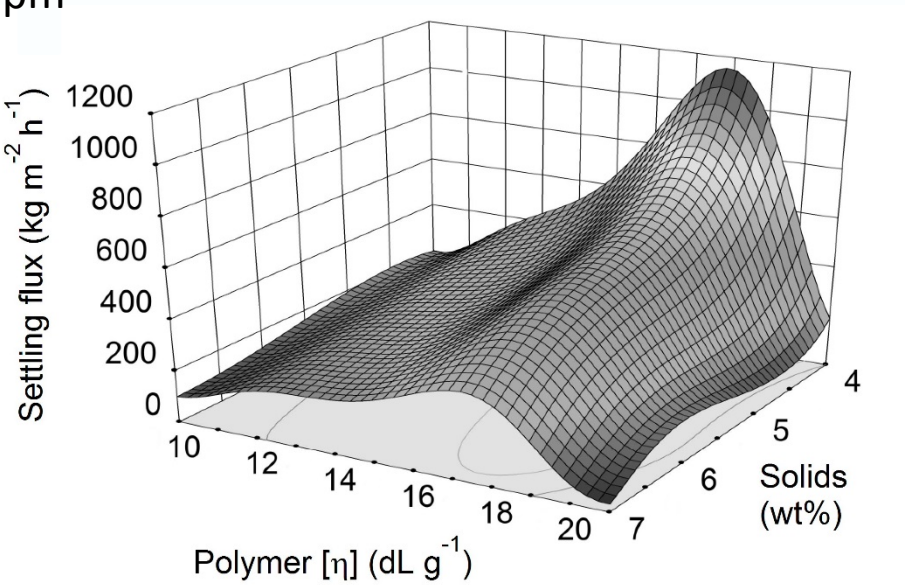
Shear Vessel for assessing flocculant performance



Low solids - Effect of mixing time/solids conc^{n}

200 rpm

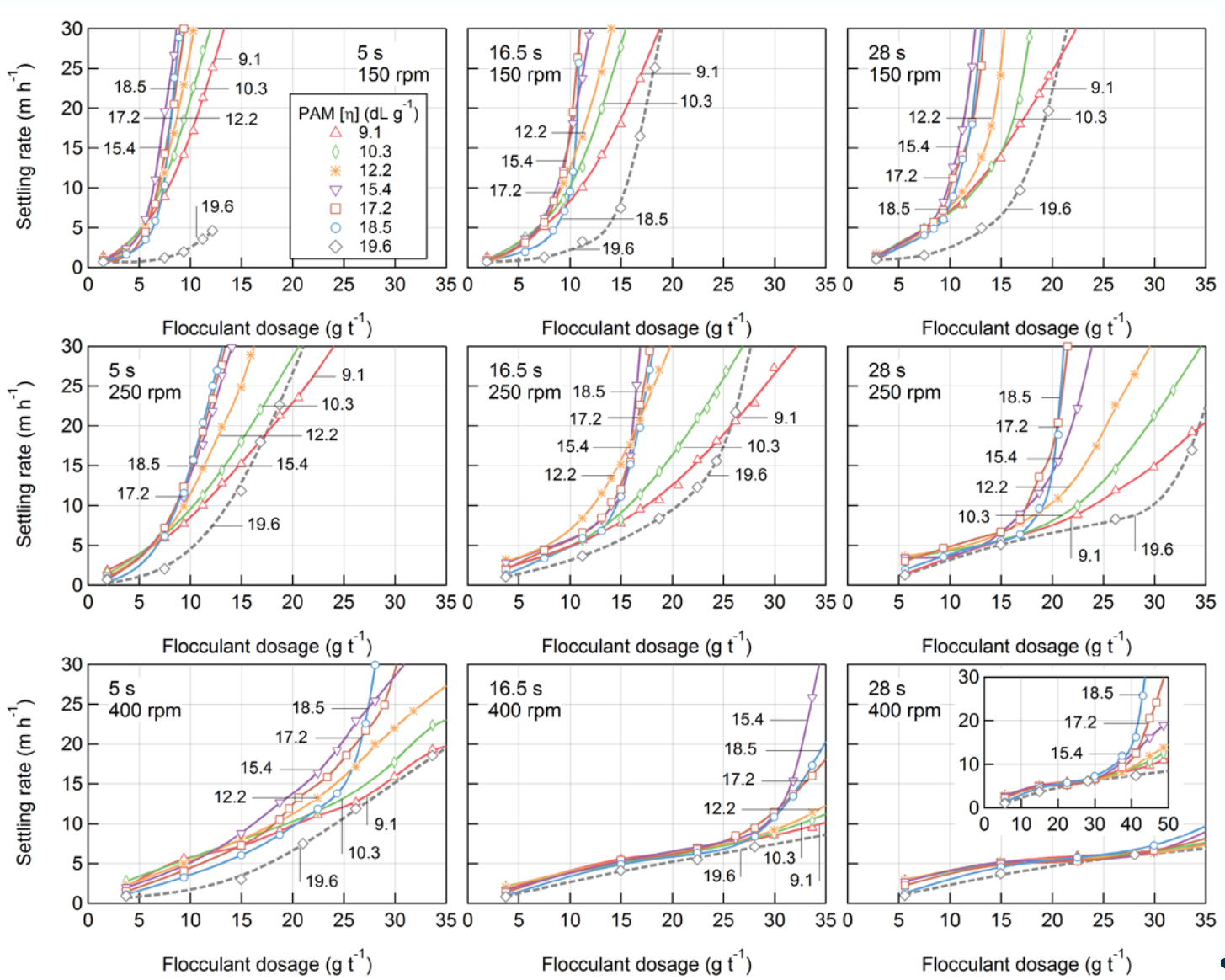




- Highest MW PAMs are not necessarily the best performers.
- Irreversible aggregate breakage under prolonged shear.
- Leads to a reduction in effective settling rates.
- Increasing solids leads to progressive decline in settling flux at a constant dosage.
- Same overall ranking order with increasing solids concentration.

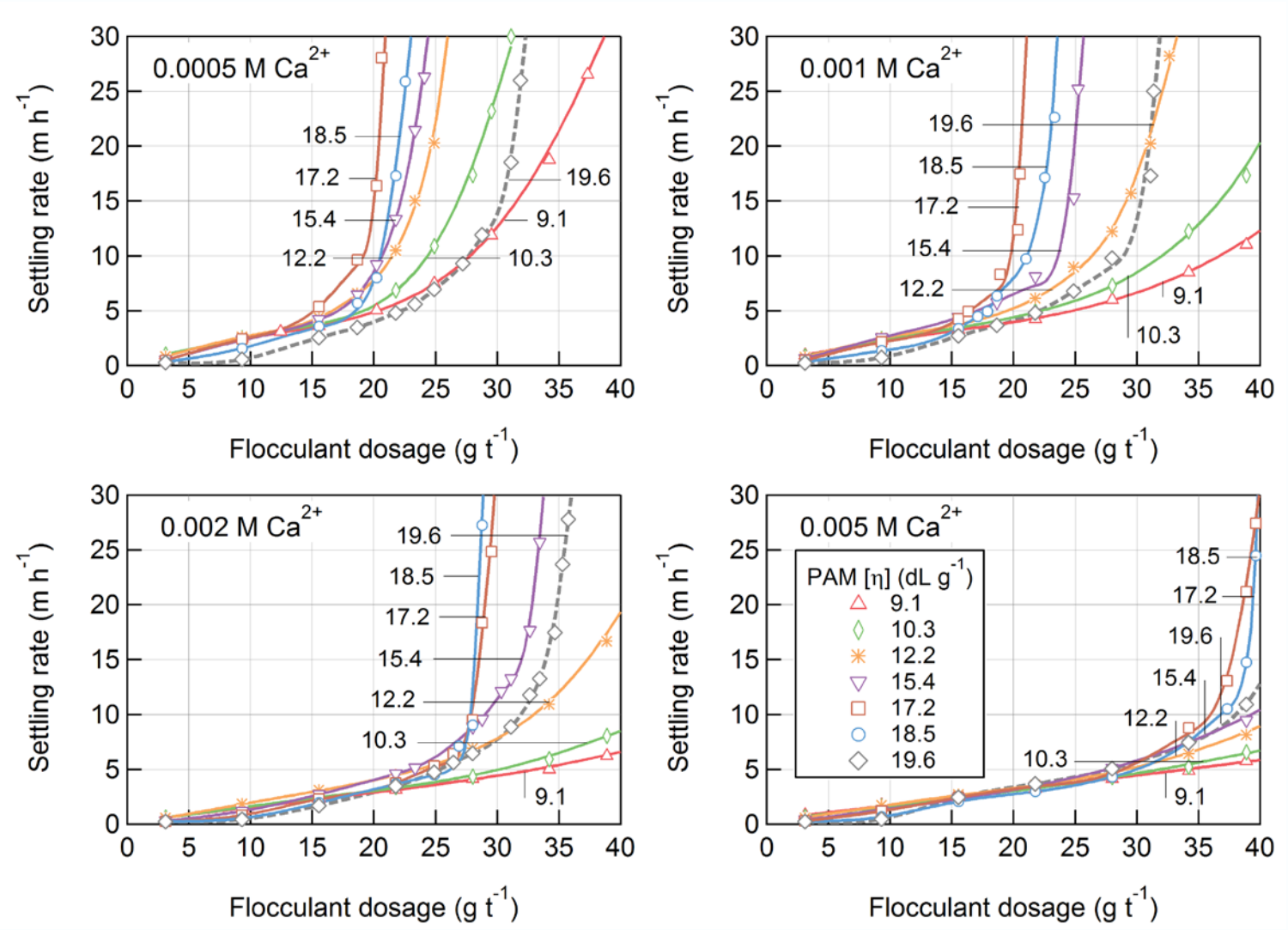
Low solids - Effect of mixing time/duration

Low Shear



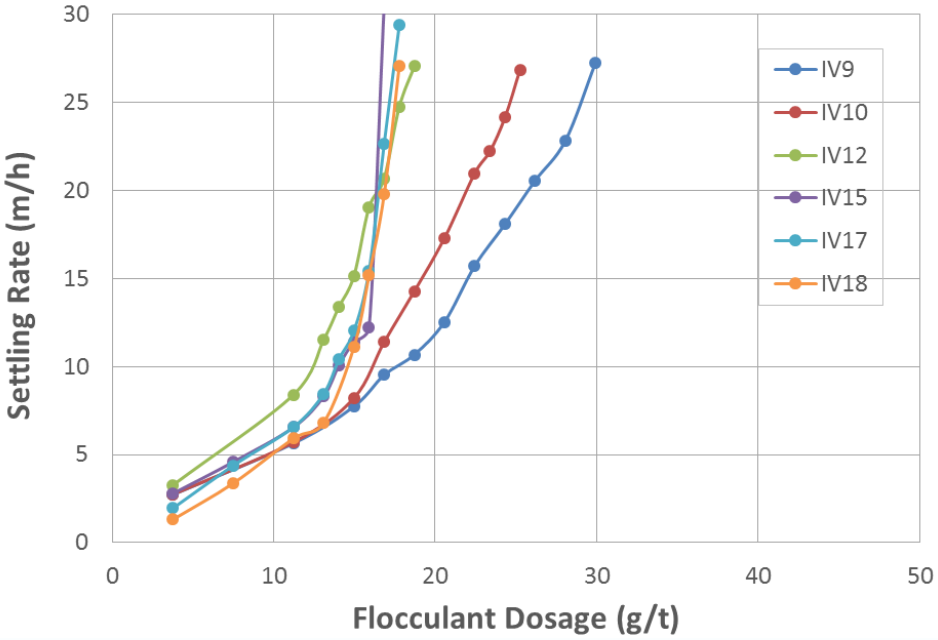
High Shear

Effect of cations in the slurry – Ca^{2+}

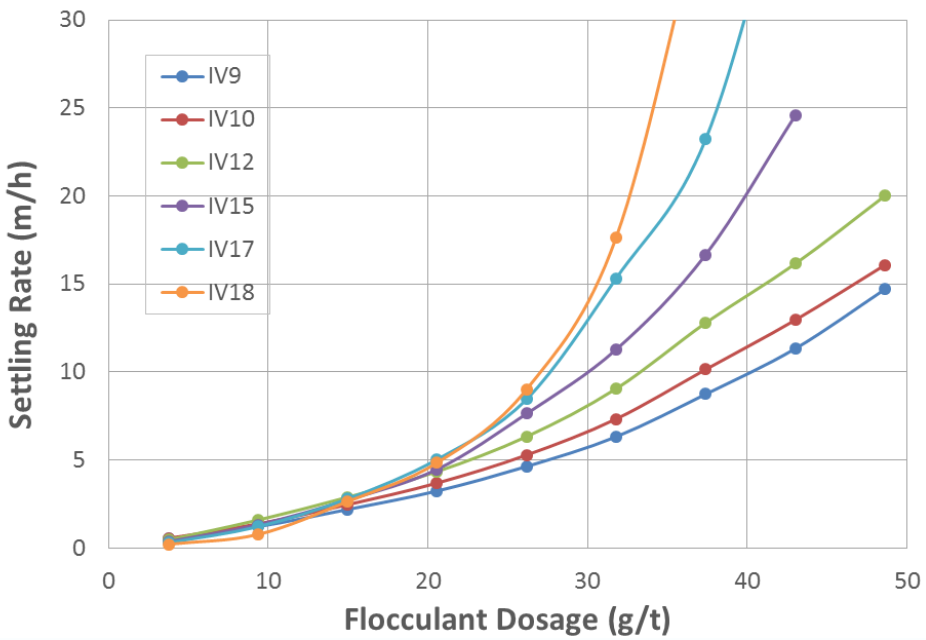


Flocculation in seawater

Freshwater

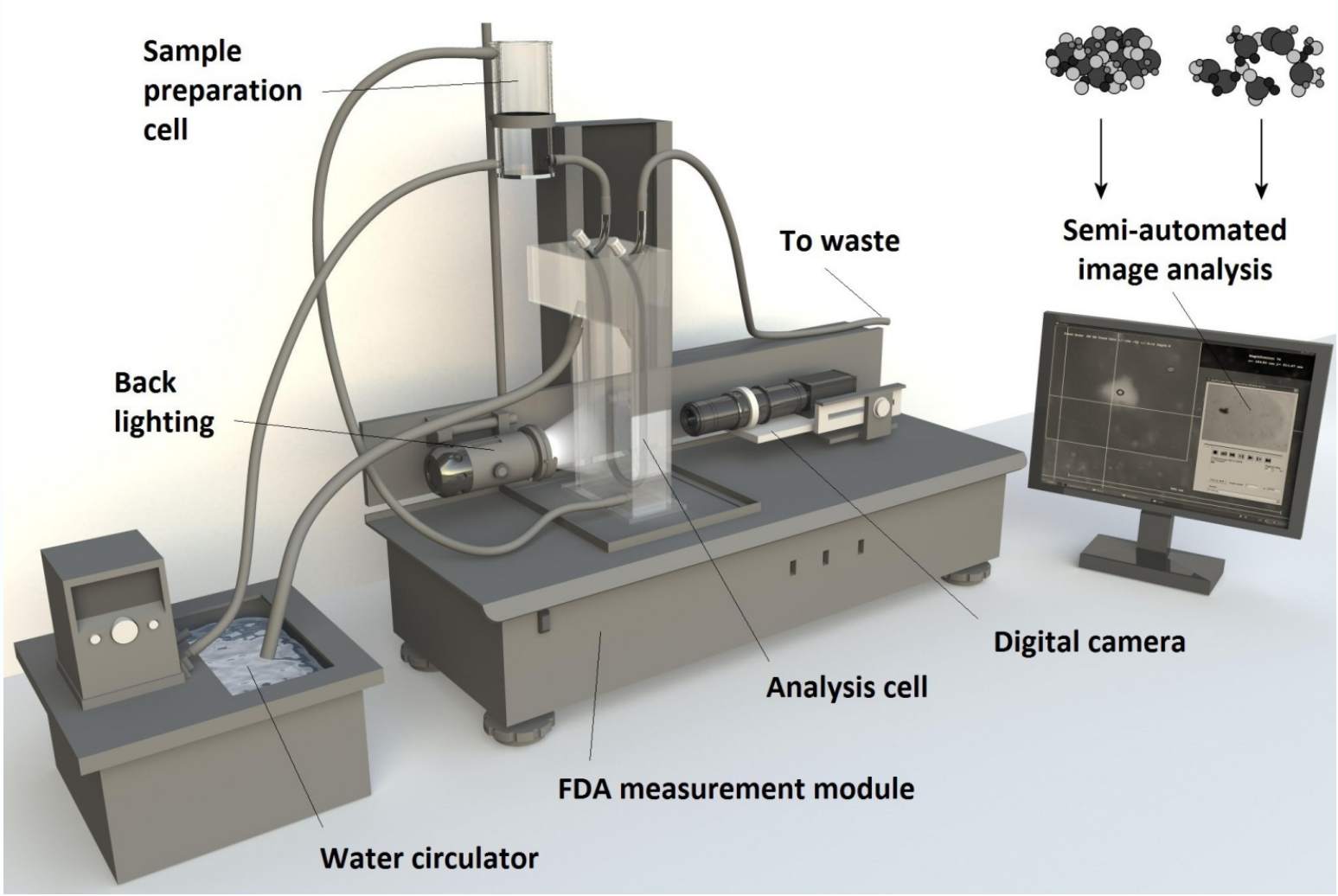


Seawater

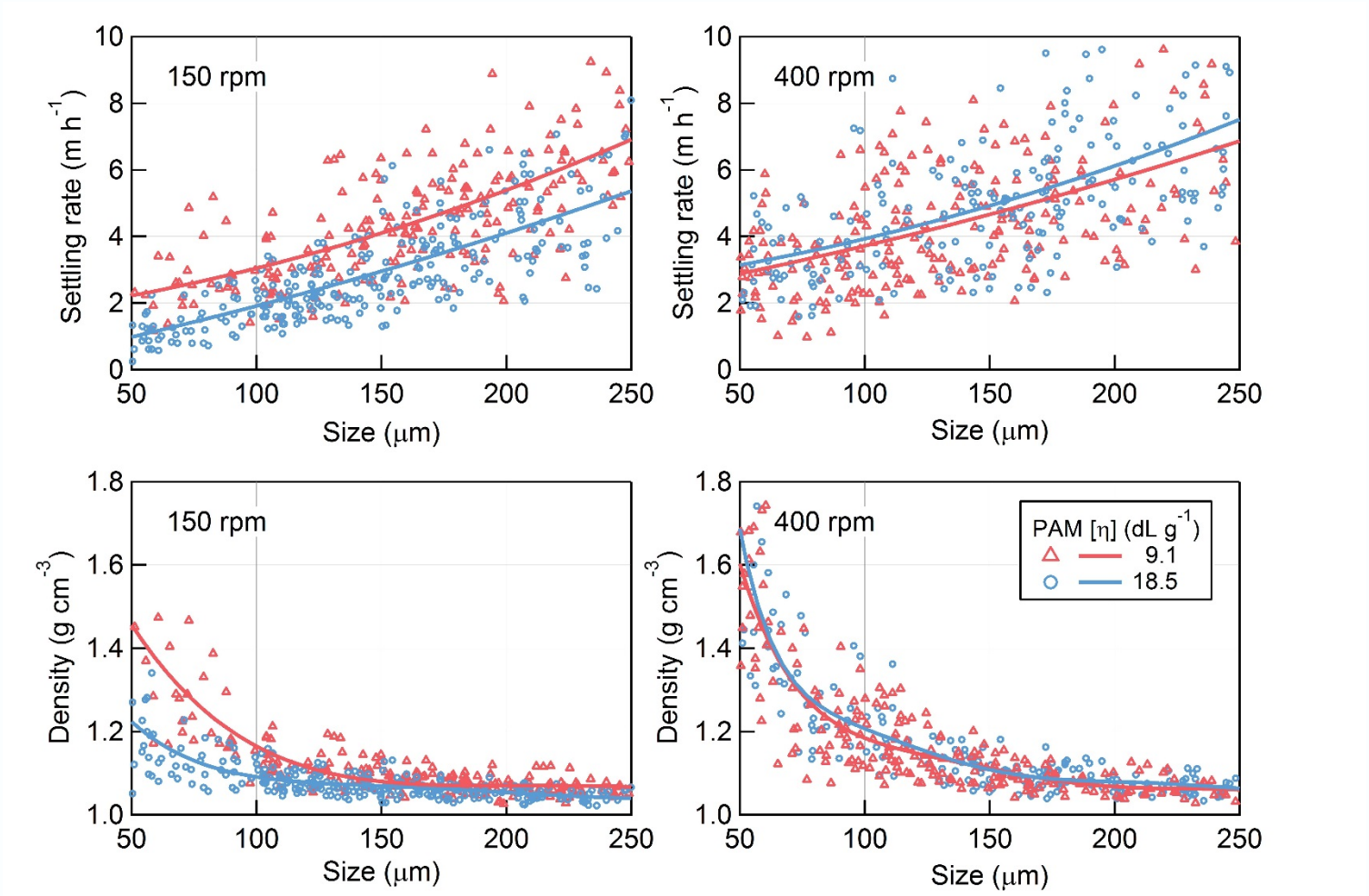


- **Required dosages are higher in seawater.**
- **Response to solids shows a high optimum solids concentration.**

Floc Density Analyser (FDA)

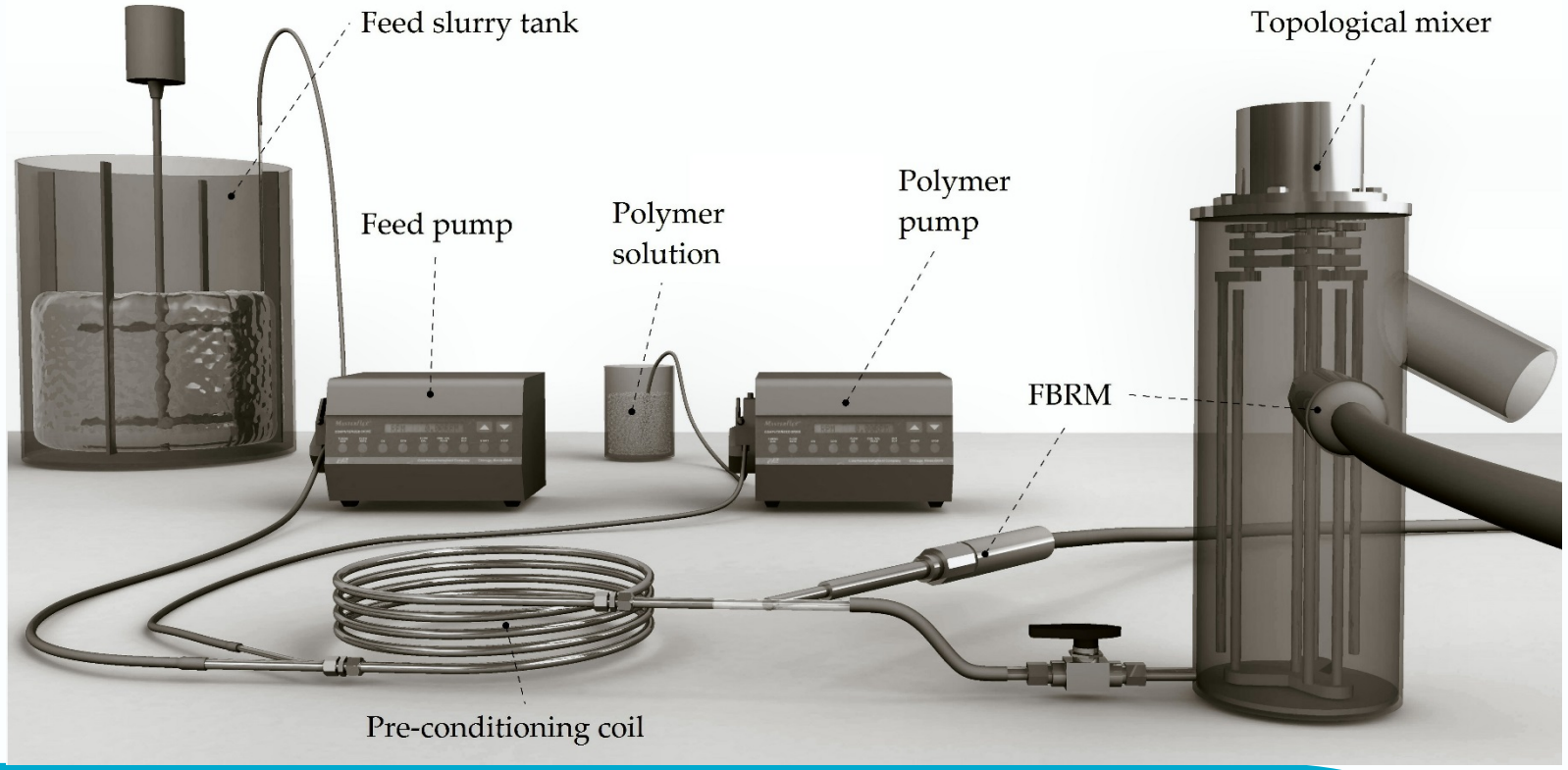


Floc Density Analyser (FDA)

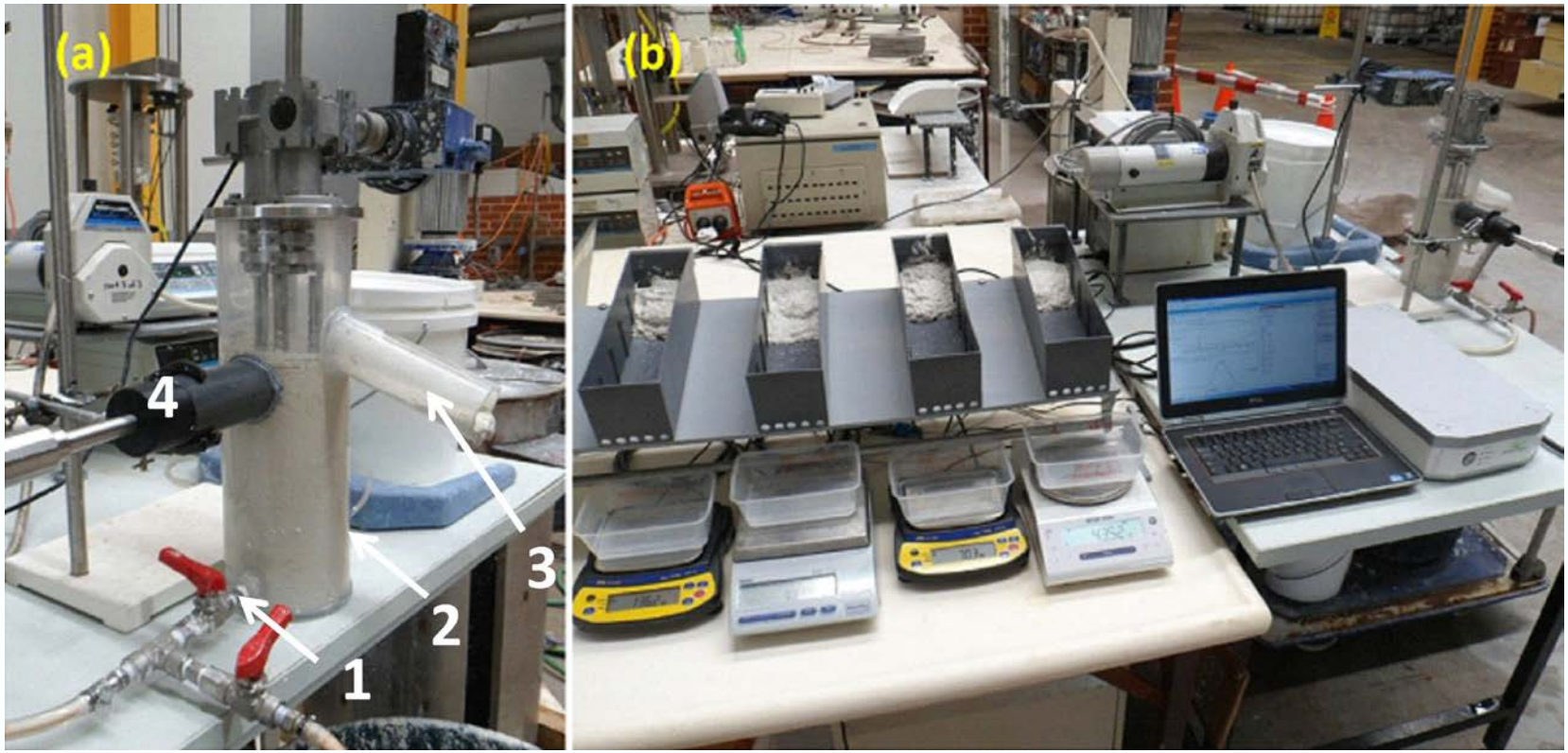


For results in seawater, higher density is confirmed, but no obvious sensitivity to flocculant molecular weight

Dosing at high solids concentrations

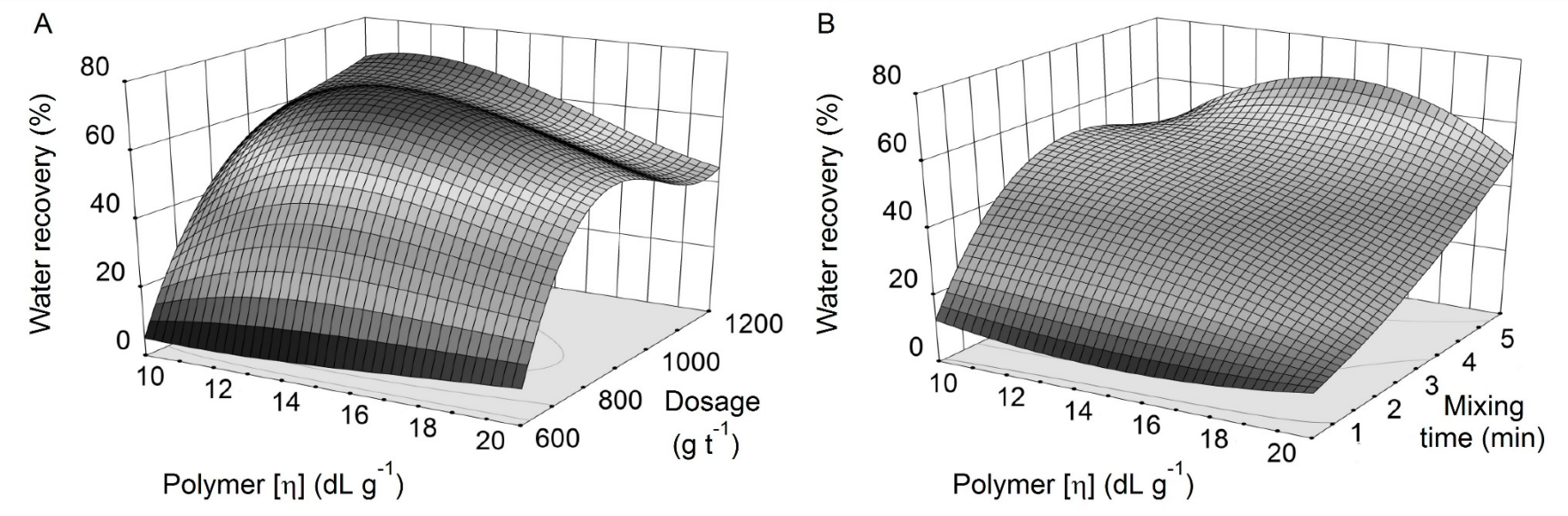


Topological mixer and deposition cells



(A) Topological mixer used to produce the thickened slurries showing (**1**) slurry inlet, (**2**) polymer sparge, (**3**) slurry outlet, (**4**) FBRM adaptor, and (B) deposition cells used for dewatering measurements.

High solids - Effect of dosage/mixing time



- Best dewatering performance from medium-high MW PAMs.
- Low MWs less sensitive to over-dosing than higher MWs.
- Different PAM MWs have distinct mixing requirements.
- High MW PAMs producing more bridges will tolerate and probably require more mixing.

Summary

- There are no bad clays, just unrealistic expectations:
  - Shouldn't try to fight physics.
  - Flocculation will normally be fine under the right conditions, but processes need to designed around what can be physically achieved.
- Lot's of people study clay flocculation, but:
  - Outputs are often artefacts of the test conditions rather being insights into the fundamentals of aggregation.
  - Looking at a lot of reagents under a narrow range of conditions risks masking true behaviour, even seeing the wrong trends.
- Changing type and properties can have significant impacts, but:
  - Test must be carefully designed and comparisons fair.
  - Too many tests raise more questions than they answer.

Acknowledgements

- BASF for ongoing access to specially prepared products and the permission to publish.
- Stephen Adkins and Danielle Meyrick (both formerly of BASF) for their assistance in arranging access to the flocculants.
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Questions?

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