Abstract No.
PD20.03

Effects of Polymer Flocculation upon Sludge Dewatering in Potable Water Treatment

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The contents of this poster are derived from research undertaken by the author while at
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Abstract

This study **quantifies the effect of polymer flocculation** (at the head of the plant) **upon the dewatering of sludges** generated in conventional **drinking water treatment**.

Coagulation and flocculation were carried out under various conditions representative of full-scale operation.
Two long-chain **polymeric flocculants** were used: one weakly cationic, the other weakly anionic.

Flocculation had **little effect on the equilibrium parameter**, 'compressive yield stress'.

► This suggests that the **internal aggregate structure was unchanged**.

Flocculation typically led to a **twofold improvement in the dynamics**, represented by the 'hindered settling function'.

► This suggests a **commensurate increase in throughput** in industry, where the processes are generally rate-limited.

1. **Introduction**

Two key steps in conventional potable water treatment are:
- addition of a precipitating **coagulant** (*e.g.* alum)
- **clarification** to separate the water from the resultant sludge.

The **sludge** from clarification is commonly seen as a **waste**. Hence further **sludge dewatering** — *e.g.* thickening, centrifugation, or filtration — can be **beneficial**, as this can maximise water recovery, and minimise the volume of sludge.

It is common to dose **polymeric flocculants** at the head of the plant **to enhance the separation**. While this action seems to improve the *kinetics*, the effects on *equilibrium* 'compactibility' are unclear. Such information is useful for predictive modelling, and can give insight into underlying mechanisms.

2. **Aim**

The objective was to **quantify the effect of polymer flocculation** at the head of the plant **upon sludge dewatering** in terms of the **separate dynamic and equilibrium contributions.**

3. **Theory**

A rigorous theoretical framework was applied to analyse behaviour [see full paper for references]. Properties were described by two parameters:

Equilibrium: **compressive yield stress**, P_y.
► Represents static strength to resist dewatering.

Kinetics: **hindered settling function**, R.
► Represents flow resistance to dewatering (opposite of permeability).

Both depend on the mass **concentration of solids**, C.

4. **Experimental**

Raw water from a Melbourne reservoir was treated in 48 litre batches in a scaled up version of a typical jar test [see full paper for details]. Two alum doses and two polymers were used:

Sample	Alum dose	Flocculant
1	high = 79 mg(Al)/L	None
2	high	10%-anionic
3	high	10%-cationic
4	low = 5 mg(Al)/L	None
5	low	10%-anionic

The conditions were otherwise comparable.
The pH was ~ 6 in all cases.

5. Results and discussion

(a) Dewatering parameters: P_y

The literature suggests that dosing flocculant leads to faster dewatering, at the expense of a reduced maximum extent.

Figure 1 shows the effects of flocculant addition on the **compressive yield stress**, P_y.

The compressive yield stresses for the three **high-alum-dose** sludges are **remarkably similar**. It strongly suggests that across all concentrations the **flocculant has no effect on the equilibrium condition**.

The $P_y(C)$ data for the two **low-alum-dose** sludges shows **some variation**. The flocculated sample appears marginally weaker in filtration, but somewhat stronger at the lowest solids concentrations.
These **apparent differences** can probably be largely **attributed to the different raw waters** used to produce these two sludges. The low-alum, anionic-flocculant sludge was generated from water similar to the high-alum sludges; the low-alum, no-flocculant sludge was generated from raw water with about half as much organic loading.

Overall the effect of flocculant on static sludge strength seems negligible.
This is *contrary* to some suggestions in the literature.

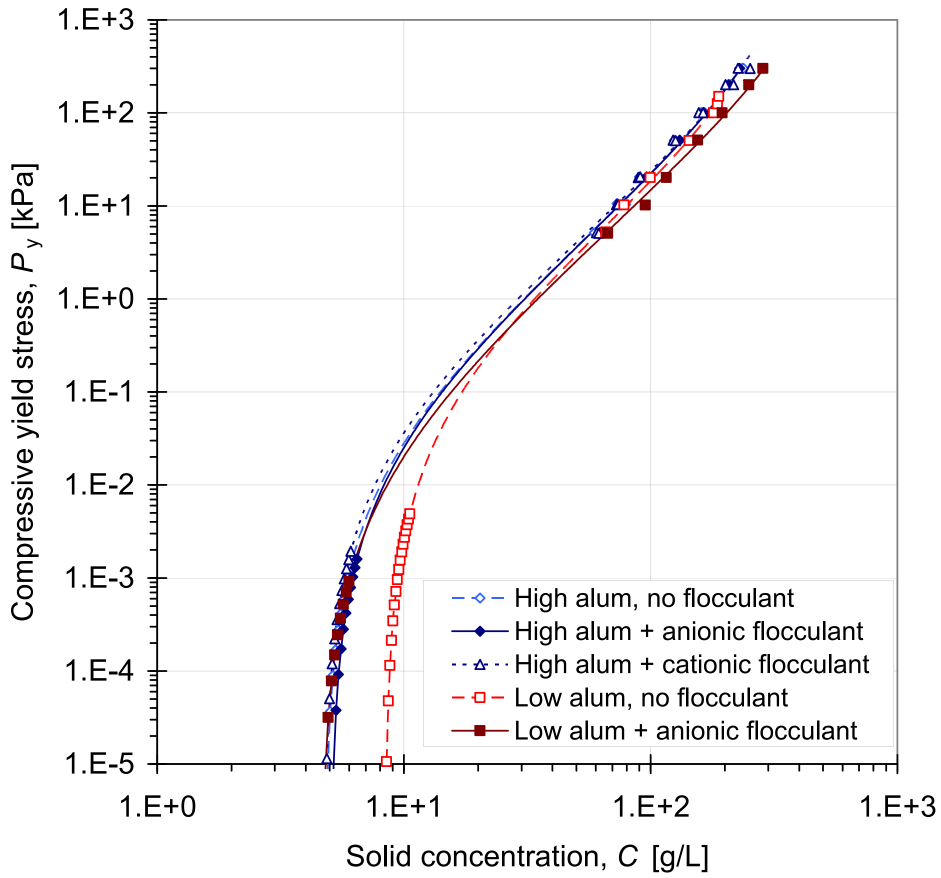

Figure 1: Compressive yield stress for two sets of sludges where flocculants were added to promote aggregation, compared to 'controls' with no flocculant.

5. **Results and discussion** *continued*

(b) **Dewatering parameters: *R***

Figure 2 shows the effects of flocculant addition on the **hindered settling function**, *R*.

There are **significant differences** between the *R*(*C*) curves — unlike the $P_y(C)$ curves.

The **flocculated** sludges tend to have **lower values of *R***, implying **less resistance to dewatering**.
The trend is **consistent** across the two types of flocculant used, and across the range of observed *C* — except for the portion of the low-alum-dose curves at low concentration.

This is the *expected* trend (based on literature reports and industrial experience).

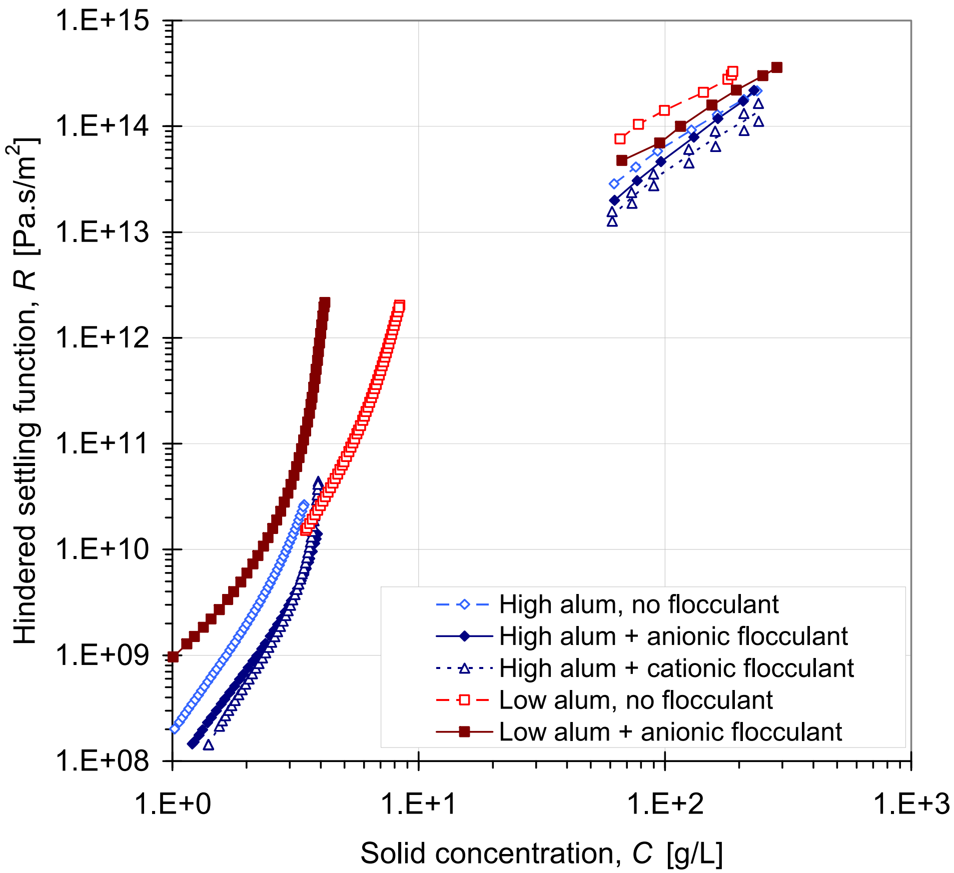

Figure 2: Hindered settling function for two sets of sludges where flocculants were added to promote aggregation, compared to 'controls' with no flocculant.

5. **Results and discussion** *continued*

(c) **Physical mechanism**

Flocculant addition had little effect on equilibrium properties, although the dewatering kinetics changed significantly.

Unaffected $P_y(C)$ seems to suggest an unchanged internal structure of the particulate network and constituent aggregates, while some sort of structural change is necessary to explain the change in $R(C)$.

Figure 3 illustrates how a structural change could reduce $R(C)$ without affecting $P_y(C)$.

For this *simplified* arrangement:
- the **solid concentrations**, C, of each system are **identical**;
- the **vertical resistances** to static mechanical stress are **the same**;
- the **resistance to flow** in configuration "**a**" is much **greater** than that in configuration "**b**".

In the illustration, the aggregates are all the same; only their **packing is different**. A mechanism of this nature is compatible with the experimental protocol adopted in the present work.

Applying analogous arguments to the *real system* leads to the conclusion that the **flocculant is predominantly located on the periphery of particle clusters, which affects their binding properties, and hence the packing efficiency**. This in turn modifies the characteristic hindered settling function associated with the particulate system at any given C.

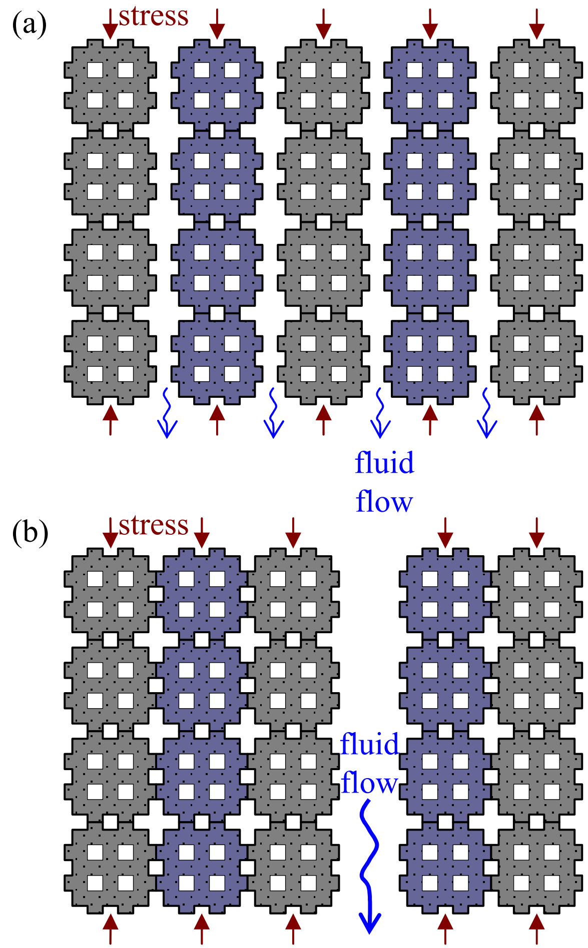

Figure 3: Schematic illustration of the effect of macroscopic sludge structure on strength and hydrodynamics.
(a) Uniformly spaced stacks of aggregates.
(b) Unevenly spaced stacks of aggregates.

5. **Results and discussion** *continued*

(d) **Industrial implications**

Industrially-operated dewatering processes tend to be **rate-limited**.
The sludge is not exposed to the dewatering 'force' for long enough to come to equilibrium. Instead, the dewatering is terminated at a state dictated by the available time and the dewatering rate.
It is not necessary for equilibrium properties — $P_y(C)$ — to improve in order to reduce the 'final' moisture content of sludge out of the device, provided the kinetics are enhanced.

Present results indicate that **prior flocculation would result in a greater extent of dewatering in practice** — even if $P_y(C)$ is not changed. A larger C would be attained over the same period of time.
Alternatively, the decrease in dynamic resistance, $R(C)$, could be exploited to **enhance throughput** by reducing the processing time — equivalent to increasing the flowrate, for continuous processes — to achieve the **same output *C***.

In principle the throughput gains should persist downstream. However *e.g.* shear imparted in channels could disrupt some benefits. A further action to address this is to dose a '**conditioning**' polymer downstream into the thickened sludge to improve *e.g.* filtration performance.

A complete assessment needs to consider the difference in operating costs both upstream and downstream.

6. **Conclusion**

Compressive yield stress (a measure of strength) showed **no significant difference** for sludges with and without flocculant.

Hindered settling function (inversely related to permeability) was **twice as favourable for flocculated sludges**, across the full range of concentrations for each flocculant.

Physically this suggests that, the **polymers attached to the outside** of the aggregates, and **did not affect internal structure**.

In **industrial dewatering processes**, which are generally rate-limited, flocculation at the head of the plant should allow the **same factor of improvement in throughput** as seen for the improvement in permeability.

7. **Acknowledgements**

I acknowledge staff at The University of Melbourne, including Peter Scales, David Dixon, Shane Usher and Ross de Kretser, for previous support. The Australian Research Council and The University of Melbourne funded my scholarship. The ARC also funded the PFPC as a Special Research Centre. The research project was sponsored by United Utilities and Yorkshire Water. Melbourne Water assisted in obtaining raw water samples. Ciba Specialty Chemicals (Australia) provided a flocculant sample. CSIRO funded this Ozwater '10 presentation.