Preserving CMP Slurry Health

The Impact of Pump Technology on Advanced CMP Processes

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How is slurry health preserved or lost?

Slurry health — the physical and colloidal properties that dictate whether a slurry still performs as formulated: working particle size distribution, the large-particle tail, zeta potential, % solids, pH and specific gravity.

1. **Slurry health is managed in the distribution system, not just at the blend tank**
   The large-particle tail is what damages wafers — and handling creates it.

2. **Pump choice is the single biggest lever in the loop**
   Three pumps, nine slurries, four abrasive types, up to 1,000 turnovers — one consistent result.

3. **The mechanisms can be cavitation and/or shear**
   Manage both and there is no measurable damage.

4. **Agglomerates are costly**
   Defectivity, filter performance, filter life — all track the tail.

Why the large-particle tail still decides yield

CMP remains the enabling step for global and local planarity at 5 nm, 3 nm and into the Angstrom era.

Slurry performance depends on colloidal stability — electrostatic and steric repulsion holding the abrasive apart.

The working particle size distribution is not the primary risk. The risk lives in the tail: the handful of aggregates in the 0.5 – 2 µm range.

Those particles produce micro-scratches, which disrupt aerial image focus in subsequent EUV layers, drive CD error, and cost yield.

0.5 – 2 µm

Where handling-induced aggregates concentrate — above the traditional 500 nm removal target

0.56 µm → 0.15 µm

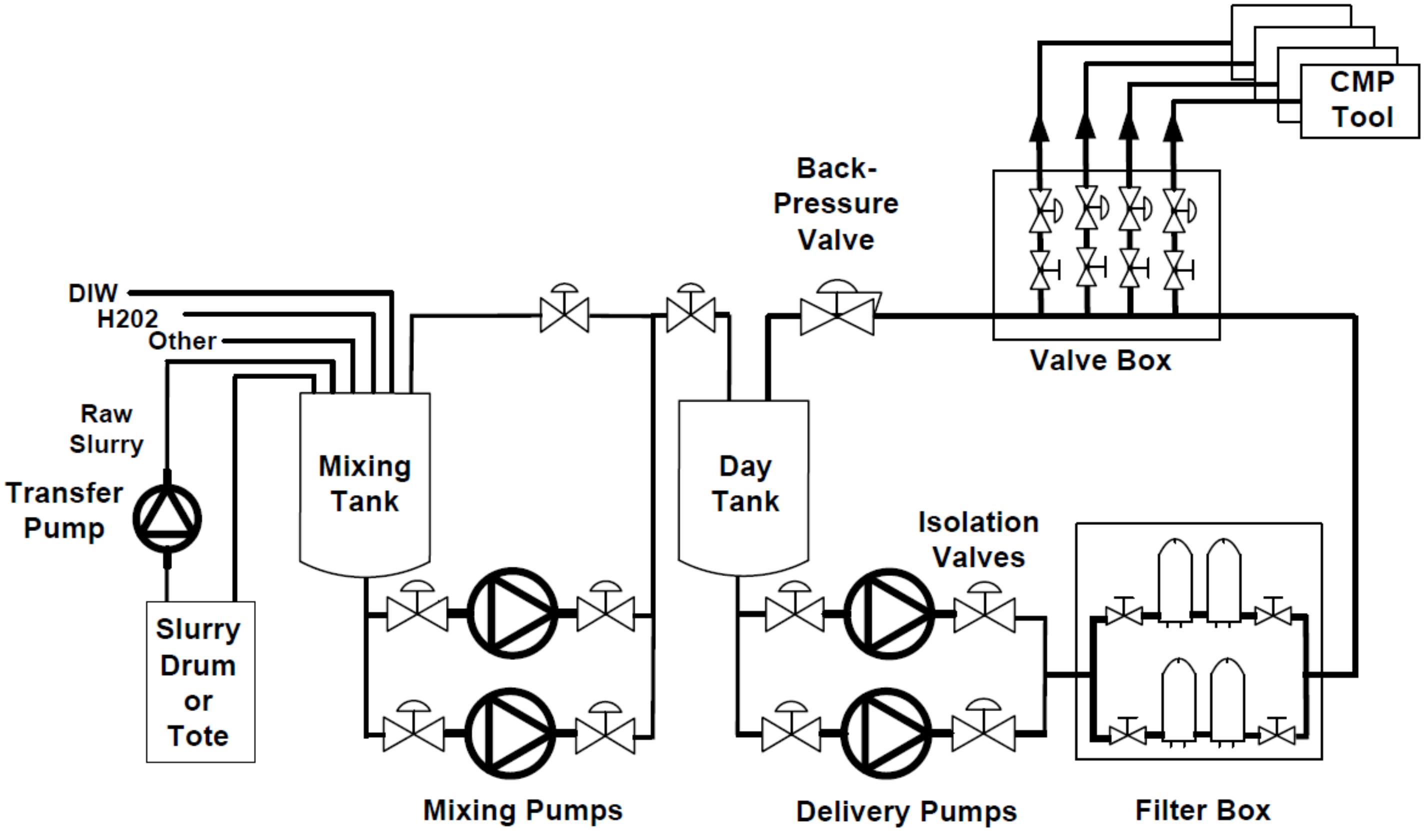
Single particle optical sizing (SPOS) detection limit then, and now. The measurement has improved, but the mechanism is still a challenge.

12 of 14

CMP tests where higher LPC meant more scratches (7 of 7 semiconductor, 5 of 7 hard-disk)

Sources: CTA Pub #114, Table III; Entegris, Filtration Characteristics of CMP Slurries; IRDS 2024 Yield Enhancement.

The slurry sees the same components hundreds of times



Typical slurry mixing and distribution system. Source: CTA Pub #114, Figure 1.

Global loop reality

- 10–30 lpm continuous recirculation
- Consumption sets the turnover count — not the pump
- ≈ 100 turnovers before a liter reaches a platen — more when tools idle or the loop is oversized
- Every turnover re-exposes the slurry to the same pump, valves and fittings

Two distributions, two instruments

Working Particle Size Distribution (PSD)

- Dynamic light scattering (DLS)
- Volume-weighted mean and 99th percentile
- Describes the abrasive that does the polishing
- Barely moves during handling — which is exactly why it can be misleading.

Large-particle tail — reported as Large Particle Count (LPC)

- Single particle optical sizing (SPOS), historically with in-line dilution
- 0.56 µm to 10 µm then; SPOS now reaches 0.15 µm with little or no dilution
- Parts per 10^6 of the total population
- Moves by orders of magnitude during handling — and tracks defects

If you only monitor the working PSD, a slurry can be badly degraded yet still look in-spec.

Methods per CTA Pub #60 §2.1. Current capability per Entegris AccuSizer FX Nano and Spheryx xSight.

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1. The impact of pumps on slurry health

Bellows, diaphragm and magnetically levitated centrifugal pumps, compared under matched flow and pressure

Three pump types — and one widely held assumption

Bellows

with pulse dampener

- Positive displacement
- Low stroke rate
- Check valves on every stroke

Diaphragm

with pulse dampener

- Positive displacement
- Low stroke rate
- Check valves on every stroke

Maglev centrifugal

Levitronix® BPS-3 / BPS-4 (Successors: BPS-600 / BPS-2000)

- Bearingless, no seals
- High rotational speed
- Continuous, non-pulsed flow

Typical perceptions:

- Bellows and diaphragm pumps are “low shear” because they run slowly, so they must be gentle on slurry.
- Maglev pumps spin at thousands of rpm, so they must generate high shear and damage the slurry.

Both perceptions turn out to be wrong.

How the comparison was run

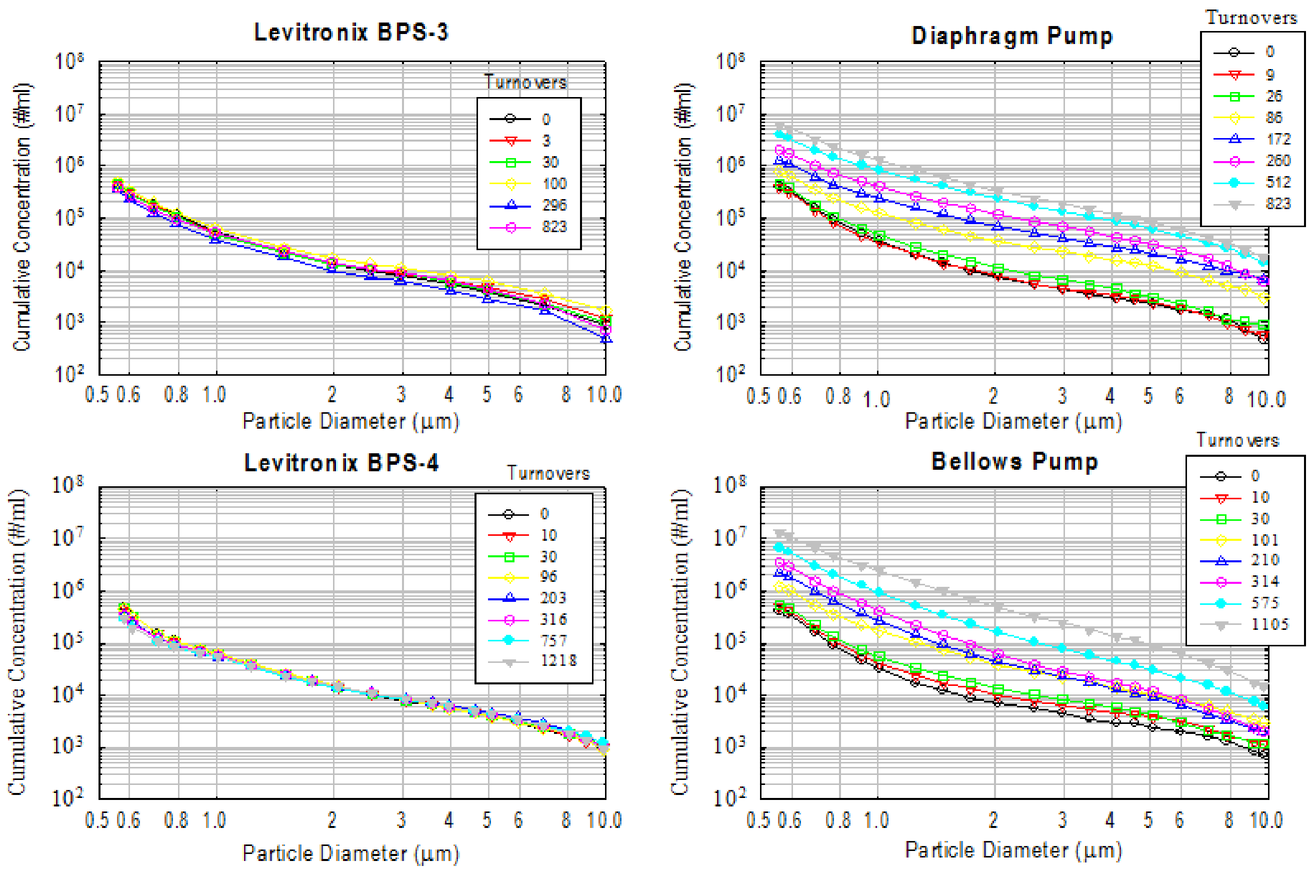
9	commercial CMP slurries
4	abrasive types
30 lpm	constant flow rate
30 psig	constant loop pressure
1,000	tank turnovers
12 L	simulated loop volume

Controls that make the comparison valid:

- Flow and pressure matched across pump types — pump speed or air supply adjusted to hold both constant.
- Fumed and colloidal silica, alumina and ceria abrasives; ILD, barrier, tungsten, copper and STI applications.
- Tanks blanketed with humidified N_2 (RH > 90%), slurry held at 22 ± 2 °C, all-PFA wetted path.
- Slurry health monitored continuously by DLS and optical particle counting, not just start and end.

Sources: CTA Pub #60 §2.2; CTA Pub #67; CTA Pub #114.

Pump type dominates the tail — fumed silica slurry



Read the two columns

- Left: two maglev pumps. Curves lie on top of each other from 0 to 1,200 turnovers.
- Right: diaphragm and bellows. The whole distribution marches upward with turnover count.
- After 1,000 turnovers: LPC > 2 µm up 53× (diaphragm) and 63× (bellows).
- At 100 turnovers — a realistic global-loop figure — both volumetric pumps are already > 5×.

Source: CTA Pub #114, Figure 4 (after Litchy, Grant & Schoeb, SPWCC 2007).

Not just a one-slurry result: nine slurries, four abrasives

Abrasive	After 100 Turnovers			After 1,000 Turnovers		
	Centrifugal	Diaphragm	Bellows	Centrifugal	Diaphragm	Bellows
fumed silica	0	+	+	0	++	++
colloidal silica 1	0	0	0	0	+	+
colloidal silica 2	+	+	+	+	+	++
colloidal silica 3	0	+	+	0	+	++
colloidal silica 4	0	+	++	0	++	++
alumina 1	-	-	-	-	-	-
alumina 2	0	+	++	0	++	++
ceria 1	0	++	++	0	++	++
ceria 2	0	0	0	0	0	0
Totals with Increase	1	6	6	1	7	7
Totals with Decrease	1	1	1	1	1	1

Key: 0 = no change (0.5–2.0×)
+ = increase (2–10×)
++ = large increase (> 10×)

After 1,000 turnovers, 7 of 9 slurries showed an increased large-particle tail with diaphragm and bellows pumps. With the maglev pump, only one did.

Susceptibility varies with chemistry, not just abrasive type — one ceria slurry was the most fragile in the set, another the most robust. All silica slurries tested were susceptible.

Source: CTA Pub #114, Table I (data from Litchy, Grant & Schoeb, CMP Users Conference 2009).

Summarizing the pump comparison

20–70×

Increase in LPC ≥ 0.56 µm after 1,000 turnovers with volumetric pumps

7 out of 9

Had no change in the tail with maglev centrifugal pumps, across abrasive types

0 out of 9

Cases where the change to the LPC was worse with the maglev pump

Bellows pumps consistently induced slightly more agglomeration than diaphragm pumps.

The effect is on the tail alone. The working PSD, zeta potential, pH and conductivity were essentially unchanged in the same tests.

Rotational speed is not the variable. The high-speed pump is the one that leaves the slurry intact.

What is driving the agglomeration?

Sources: CTA Pub #67; CTA Pub #114.

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2. Mechanism — shear or cavitation?

Separating the two variables that positive-displacement pumps normally deliver together

Two potential mechanisms, normally difficult to tell apart

Shear

- High velocity gradients impart energy to colliding particles.
- If that energy exceeds the repulsive barrier, particles agglomerate.
- Plausible — and the origin of the phrase “shear-sensitive slurry.”
- Rises with pump speed and with flow restriction.

Cavitation

- Local pressure falls below vapor pressure; bubbles form and collapse violently.
- Collapse concentrates energy into a very small volume — far above the barrier.
- Occurs at suction strokes, check valves, orifices and sharp bends.
- Also rises with pump speed and with flow restriction.

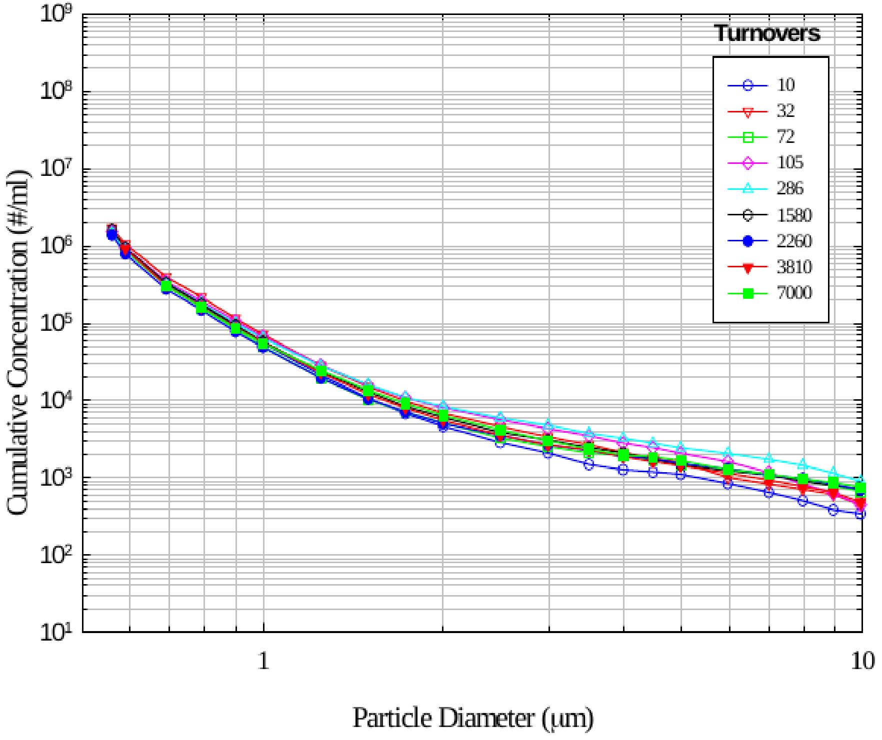
The two normally travel together.

The experiment: hold shear constant, vary only the probability of cavitation.

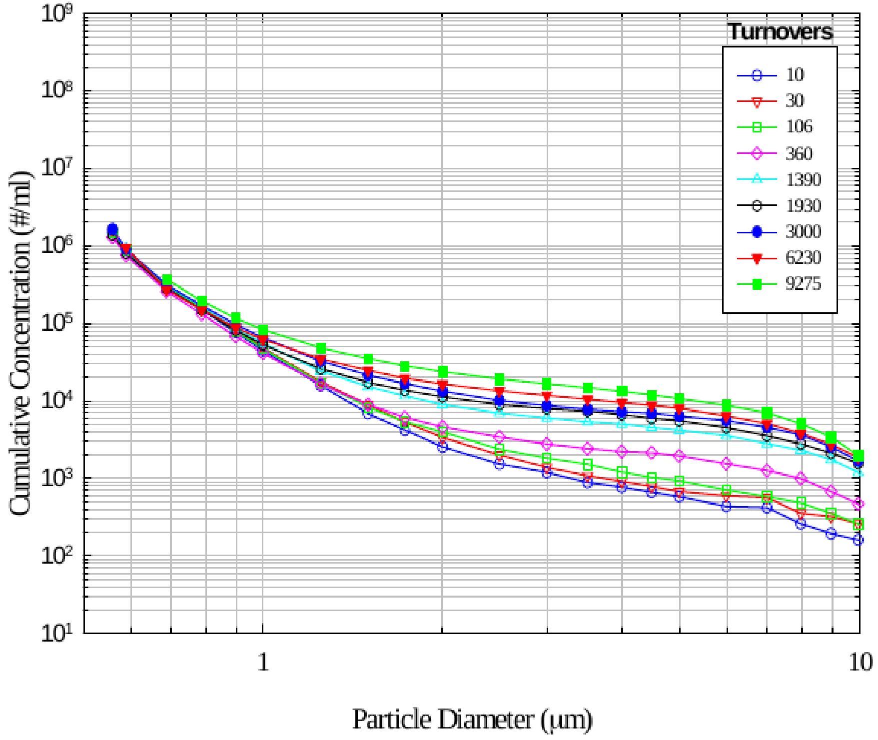
Constant shear, varied cavitation — fumed silica slurry

Maglev pump held at constant speed; only the inlet pressure was changed.

Low probability of cavitation



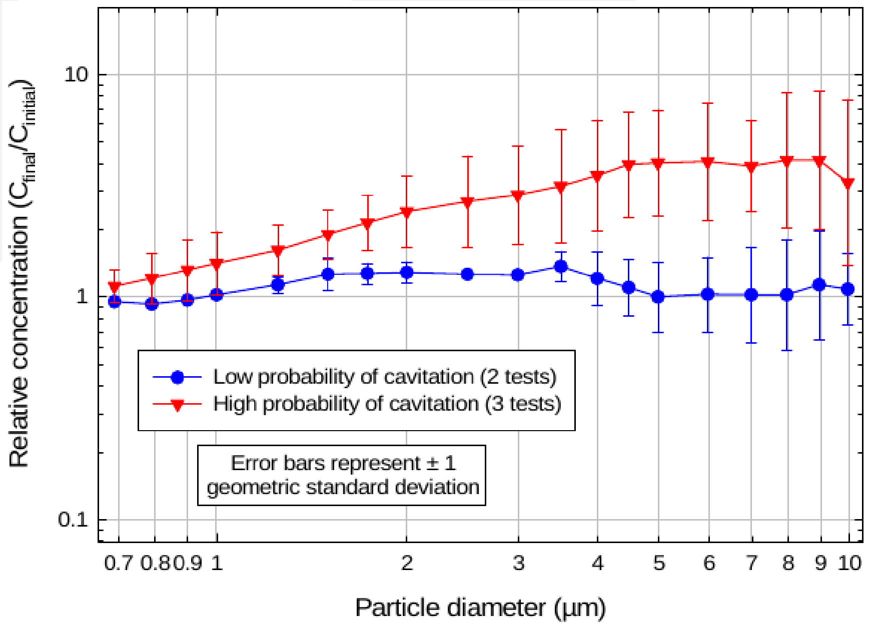
High probability of cavitation



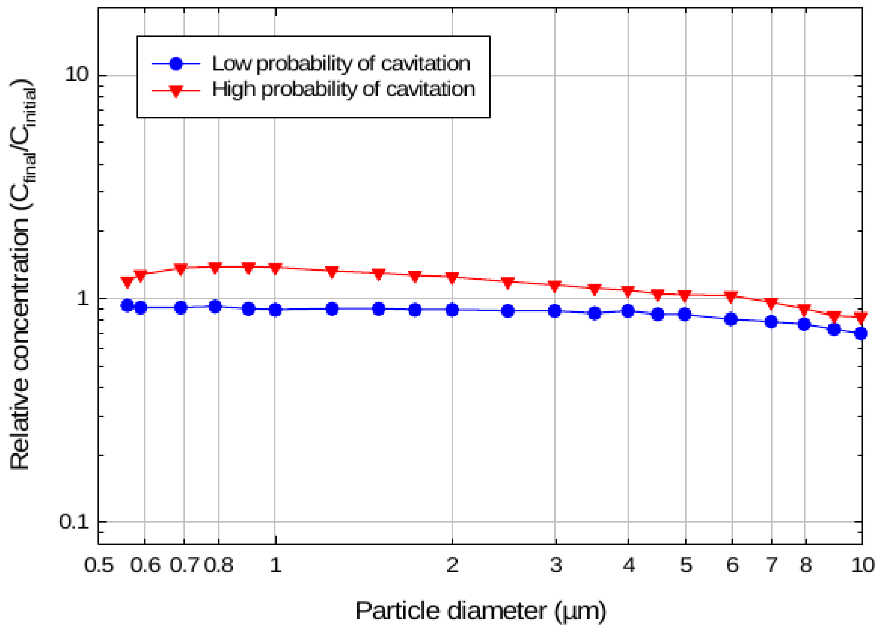
Cumulative concentration vs. particle diameter, 10 → 9,275 turnovers. Source: CTA Pub #68, Slide 22.

The same split after 1,000 turnovers

Fumed silica slurry



Colloidal silica slurry



Relative concentration: C final / C initial.

Blue = low cavitation probability

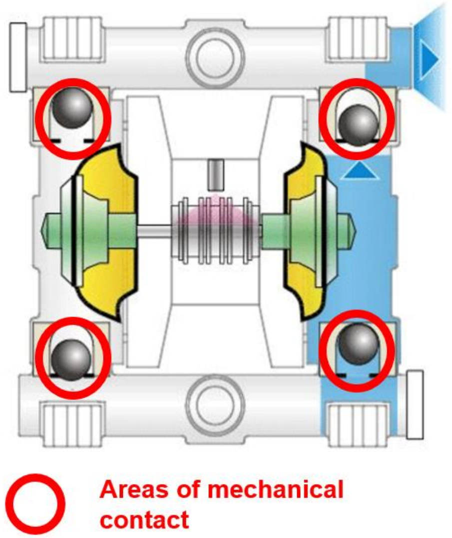
Red = high. Shear identical in both.

Under low cavitation probability the ratio sits at 1.0 across the whole size range — no damage. Raise cavitation probability alone and the fumed silica tail grows ~4×.

Source: CTA Pub #68, Slide 26.

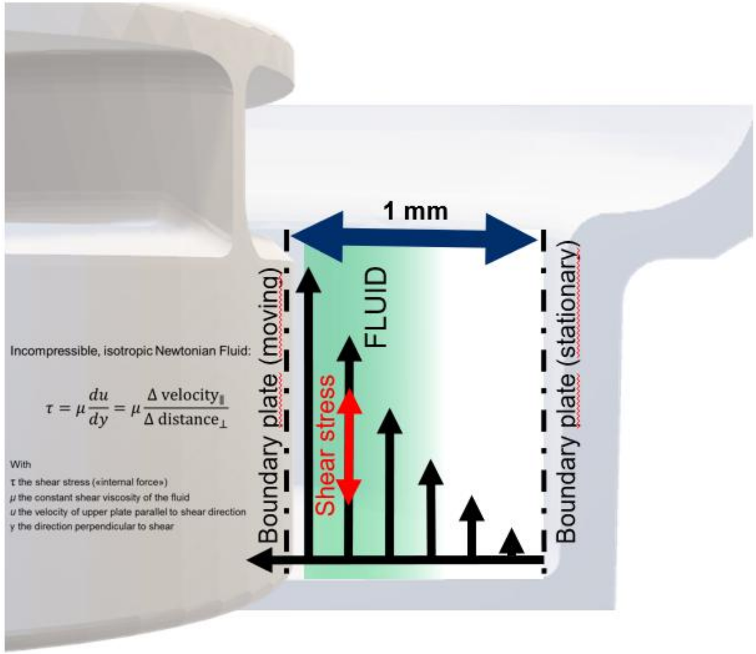
Influence of Pump Design on Shear

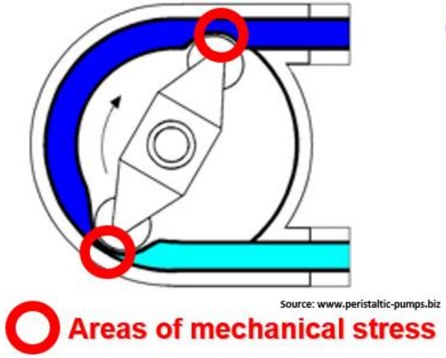
Diaphragm pump high-shear points

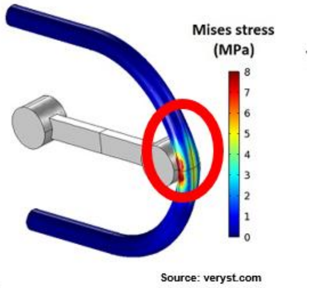


$$\tau = \mu \frac{du}{dy} = \mu \frac{\Delta\,\text{velocity}_{\parallel}}{\Delta\,\text{distance}_{\perp}}$$

Impeller-to-wall spacing of the Levitronix distributes the shear stress in the liquid







Peristaltic pump high-shear points

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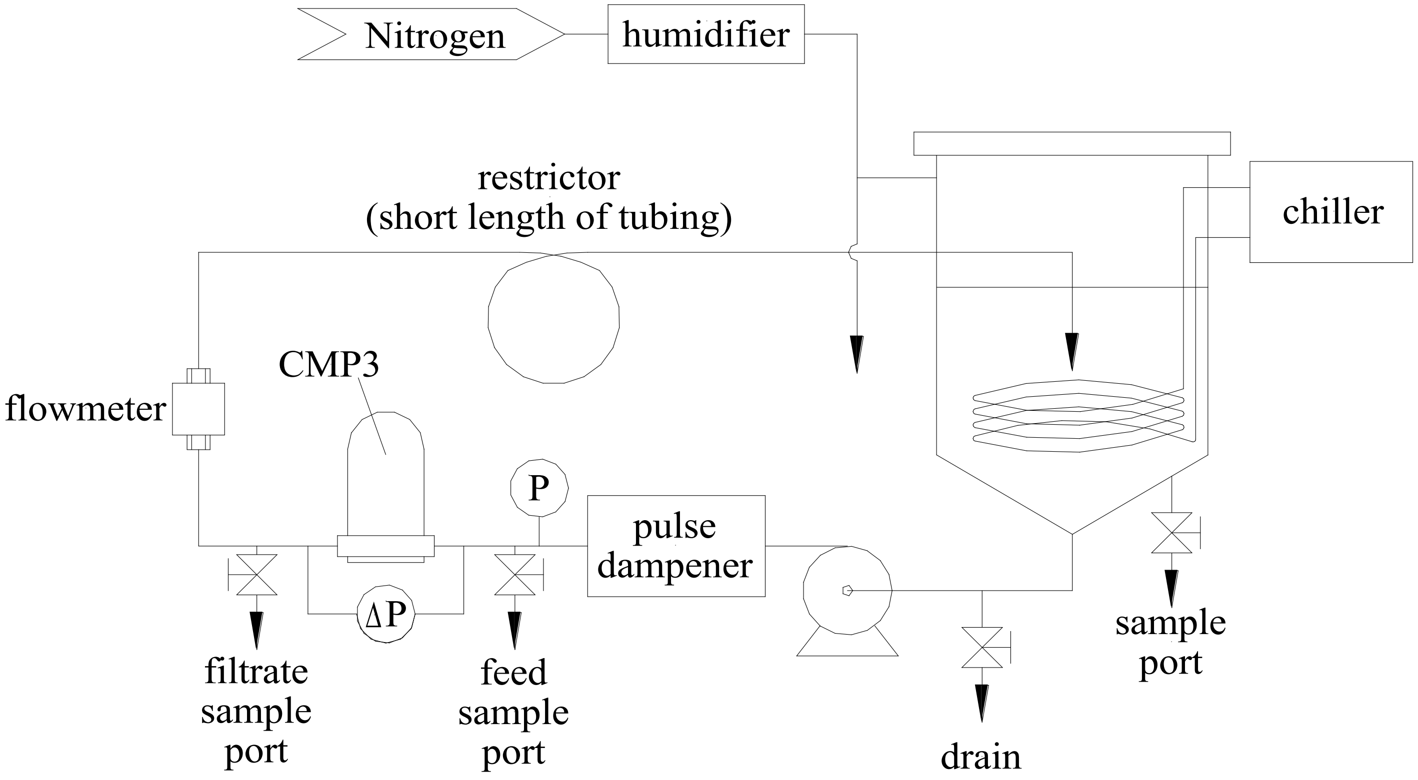
3. What's the impact of agglomeration downstream?

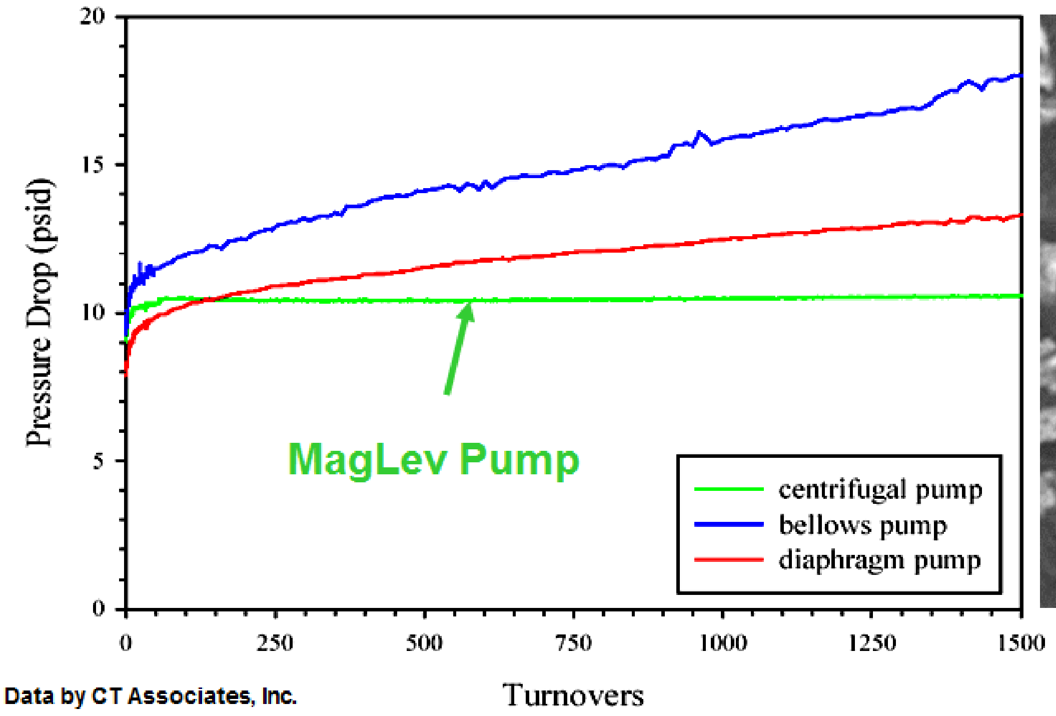
Filter lifetime, pressure-drop rate, and the limits of filtration as a remedy

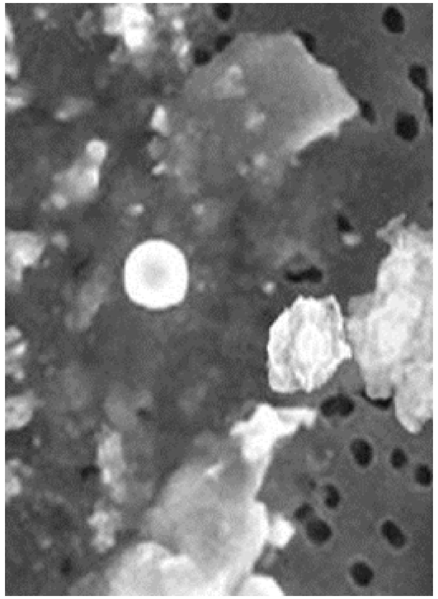
Test Configuration



- Bellows, diaphragm, and centrifugal pumps tested
- Mykrolis Planargard^{TM} CMP3
- Cabot SS12 Slurry
- 30 lpm
- 30 psi

Filters are the last line of defense





Same filter, same slurry, same flow

- Entegris Planargard™ CMP3, fumed silica, 30 lpm.
- End of life defined as ΔP rise of 10 psid.
- Maglev loop: ΔP flat through 1,500 turnovers.
- Bellows and diaphragm loops climb continuously.
- Vendors now market low-shear media — the filter itself can damage slurry.

8 – 23×

Longer filter life with maglev vs. diaphragm and bellows

Source: CTA Pub #114, Figure 8 (Litchy & Schoeb, MRS Symp. Proc. 867, 2005); inset SEM of retained agglomerates.

Ranking every element in the delivery chain

Element		Potential Impact on LPC		
		Particles >0.56 µm	Particles >2 µm	Impact Rating
Shipping Containers & Tanks	No headspace	+80%	+100%	medium
	with headspace	+100%	+1‘000%	high
Valves (10’000 cycles on volume of 25L)		+3%	+5%	low
Recirculation Pumps (1000 turnovers)	Bellows	+2‘800%	+6‘300%	high
	Diaphragm	+1‘800%	+5‘300%	high
	MagLev	- 40%	-	low
Loop Filters (3 µm, steady state, continuous recirculation)		-60%	-90%	high
POU Filters (0.5 µm, 1 pass)		-70%	- 95%	high
Dispense Pumps (1 pass)	Peristaltic	+6%	+7%	low
	MagLev	-	-	low
Loop Design (impact of extreme negative suction head of -0.83 Bar)		+10%	+500%	high

Relative impact on LPC in silica slurry. Source: CTA Pub #114, Table II.

What this ranking says

- Three elements are high-impact and negative: containers with headspace, recirculation pumps, and loop design.
- Two are high-impact and positive: loop and POU filters.
- Valves and dispense pumps are second-order — worth optimizing, not worth arguing about.
- All three negatives are design choices made once, at install.

Summary and Conclusions

Across nine slurries and four abrasive types, bellows and diaphragm pumps raised large-particle concentrations by 20 to 70× over 1,000 turnovers. Maglev centrifugal pumps did not.

Both shear and cavitation must be considered for effective slurry health management.

Positive-displacement pumps present a higher risk to slurry health based on design, specifically suction strokes and check valves.

The resulting agglomerates load filters up to 23× faster, and elevated LPC correlated with higher micro-scratch density in 12 of 14 published CMP tests.

Pump selection and suction-side loop design are facility-level safeguards for advanced-node yield — decided once, at install, and difficult to retrofit.

Thank you for your attention!

Questions?

Back-up Slides

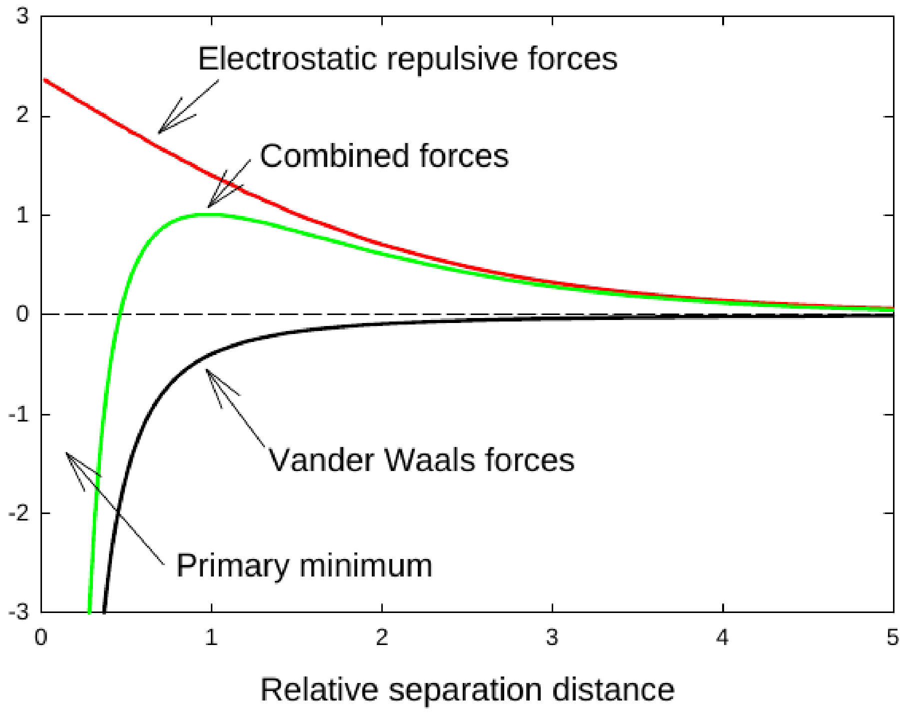
What keeps a slurry stable — and what breaks it

Abrasive particles carry high surface charge; the electric double layer plus polymeric dispersants create a repulsive energy barrier.

Cross that barrier and attractive Van der Waals forces dominate — the particles fall into the primary minimum.

That bond is effectively irreversible. Dilution and mixing do not undo it.

So the question is not “is the slurry shear-sensitive?” It is: what in the loop delivers enough energy to cross the barrier?



DLVO interaction energy. Source: CTA Pub #62, Slide 8.

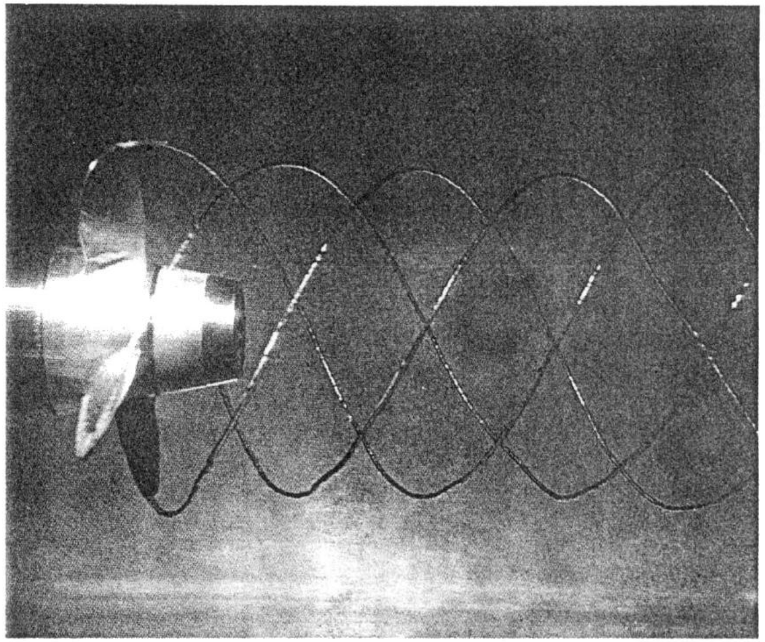
Why positive-displacement pumps cavitate

Every suction stroke pulls the chamber below atmospheric pressure — cavitation is intrinsic to the pumping cycle, not a fault condition.

Check valves open and close on each stroke; flow accelerates through a small, changing aperture, dropping local pressure further.

Only a small fraction of the fluid passes through the highest-velocity region — but over 100 to 1,000 turnovers, all of it does, repeatedly.

This also explains the field observation that bellows pumps damage slurry slightly more than diaphragm pumps.



Tip cavitation on a propeller — Garfield Thomas Water Tunnel, Penn State.
Source: CTA Pub #62, Slide 22.

What are our management opportunities?

Pump selection

- Specify maglev centrifugal pumps for global-loop recirculation.
- Judge a pump by cavitation probability, not rotational speed.
- If volumetric pumps are unavoidable, minimize turnover count.

Suction-side design

- Mount the pump below tank level; keep the inlet run short.
- Generous inlet pipe diameter, minimum bends.
- No valves on the inlet except a normally open isolation valve.
- If drawing under vacuum, do not go below −0.3 bar.

Tanks and containers

- Eliminate headspace in shipping and storage where possible.
- Blanket mixing and day tanks with humidified N_2 (RH > 90%).
- Prefer polypropylene wetted surfaces over glass.

Monitoring

- Track the large-particle tail, not just the working PSD.
- Trend filter ΔP rate of rise — it is a free slurry-health sensor.
- Baseline LPC at install, then re-measure after any loop change.

Guidance consolidated from CTA Pub #60, #62, #68 and #114.