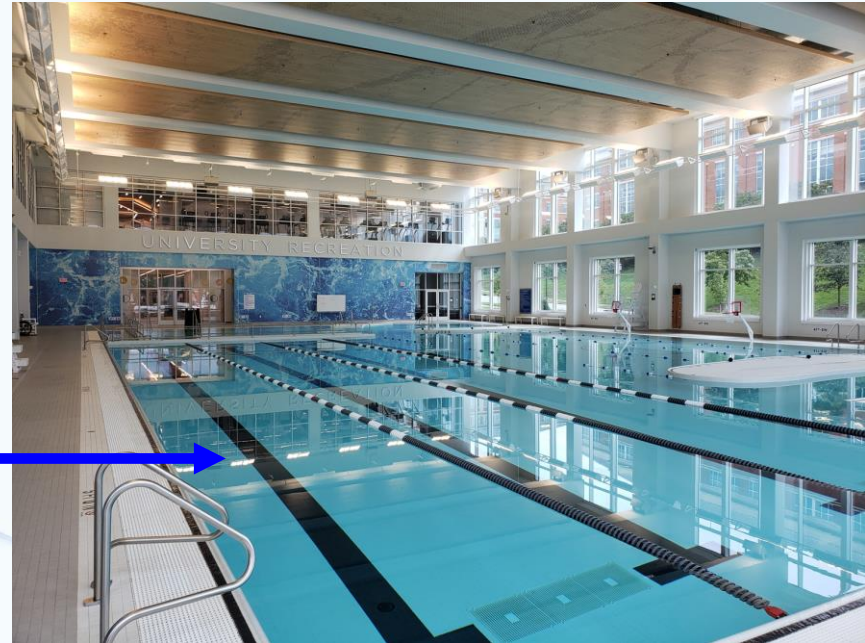
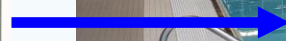


New US Filter Research: Testing VortiSand, Ultrafine Ceramic, and Coagulated Sand Filters with added Organic Batherload for *Crypto* Removal Efficiency

James Amburgey, Ph.D., P.E.



This presentation will show the impacts of media type, filter type, and bather load on particle (*Crypto*) removal from swimming pools.

The CDC lists *Cryptosporidium* (***Crypto***) as the leading cause of human waterborne disease in the US with more than **823,000** cases per year with associated direct healthcare costs of **\$45.8 million**.



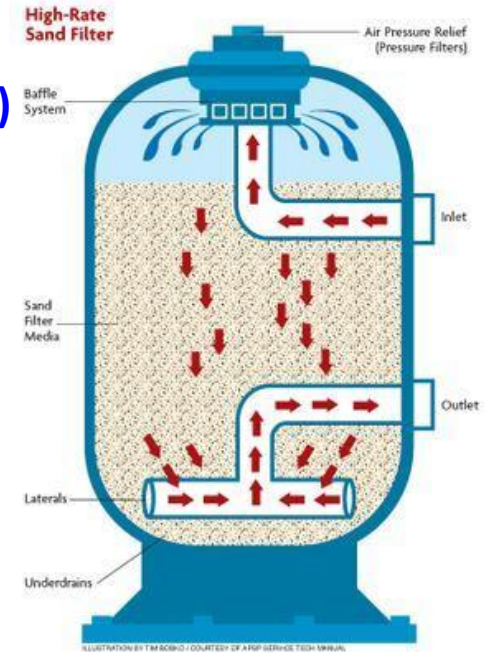
Prior Research (1 of 2)

Sand Filtration (US)

- Shown to be ineffective with only 0.19 Log (36%) removal of *Cryptosporidium* sized particles (Amburgey 2012)

Sand Filtration + Coagulation (UK/EU)

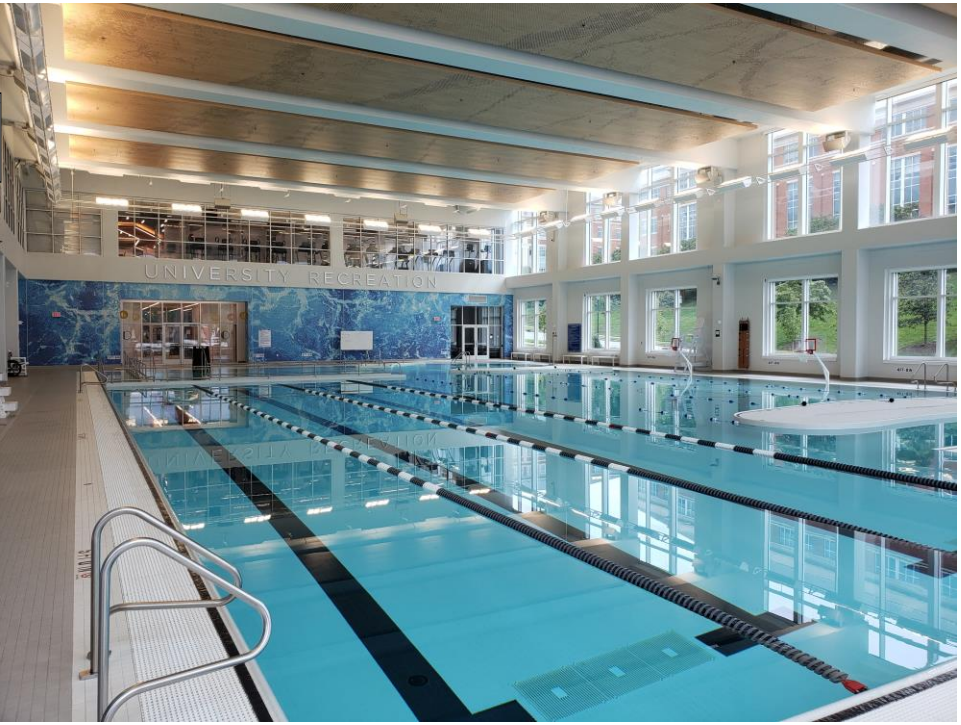
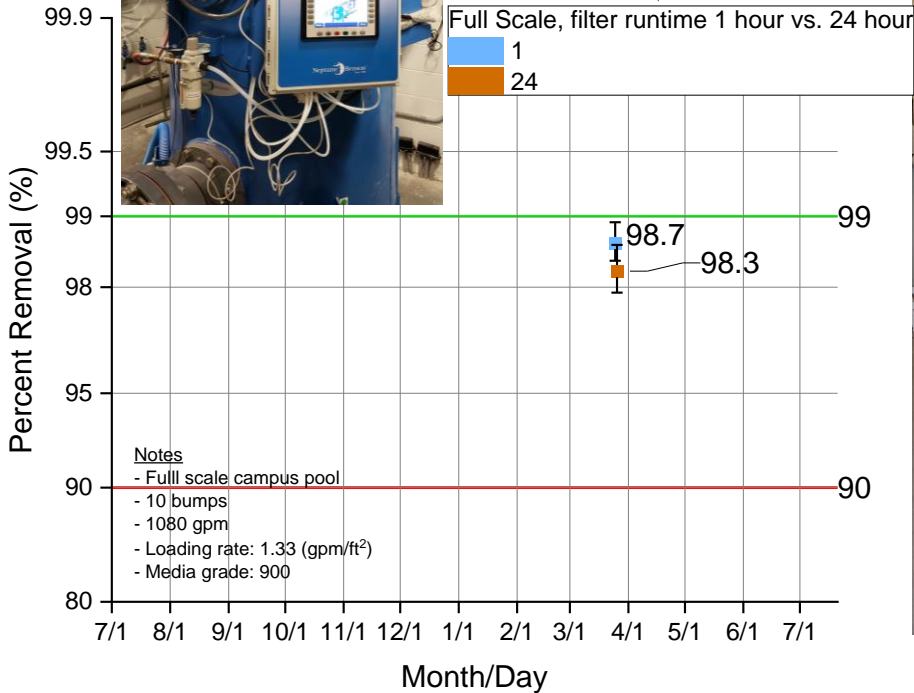
- Sand filtration with coagulation using poly aluminum chloride (PACl) can significantly increase the removal of Crypto-sized particles. With coagulation, >99% removals were achieved (Croll et al. 2007, Amburgey et al. 2012, Lu & Amburgey 2016)



Source: Bob Dumas, 2008, *The Workhorse*.
https://www.poolspanews.com/how-to/design-construction/the-workhorse_0

Prior Research at the Campus Pool in Charlotte

98.5%

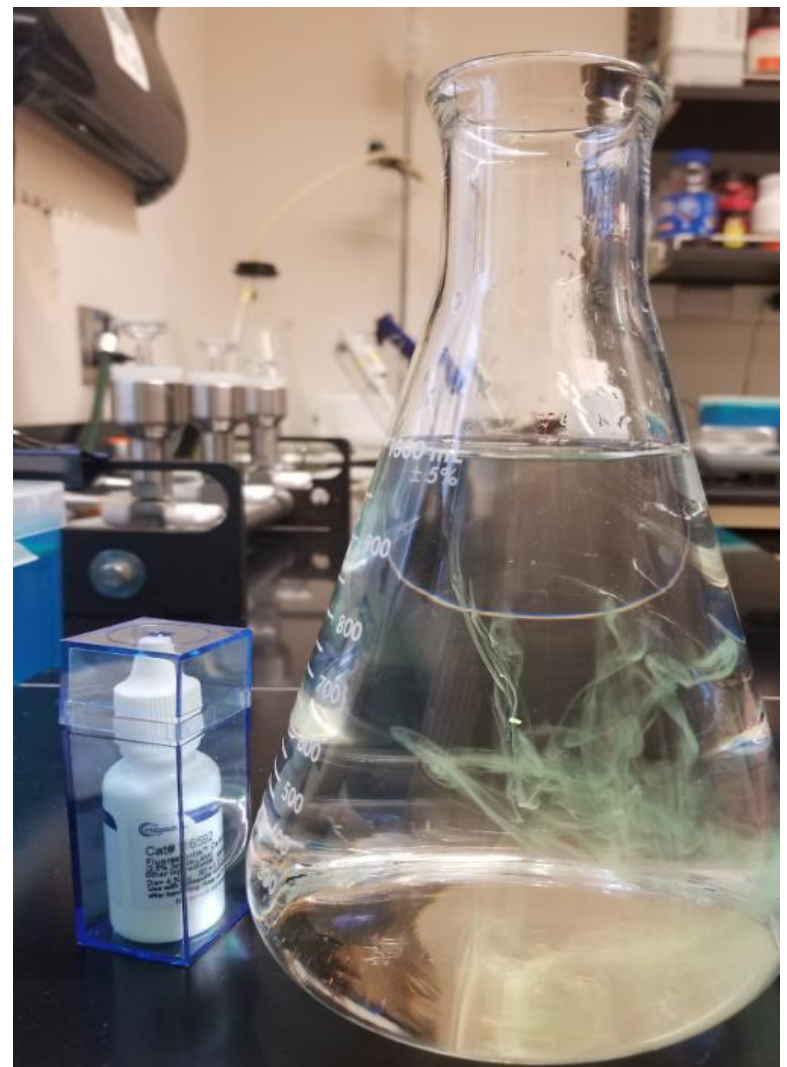


Four Types of Filters Tested

Media Depth	Media Type
12" *	Sand
24"	Ceramic
36" **	Sand
Vortisand	Vortisand

* Performed at 2 & 48 Turnovers
** Performed at 1 & 3 Turnovers

Filter removals of 4.5-micron diameter (fluorescent) polystyrene microspheres



Influent samples						
	time (min)	sample number	dose (mL)	count	#/mL	average
Three Sample Times	3	1	10	121	12.10	11.13
	3	2	10	127	12.70	
	3	3	10	86	8.60	
Triplicate Samples	7	1	10	112	11.20	10.33
	7	2	10	106	10.60	
	7	3	10	92	9.20	
	11	1	10	90	9.00	
	11	2	10	107	10.70	
	11	3	10	104	10.40	

1

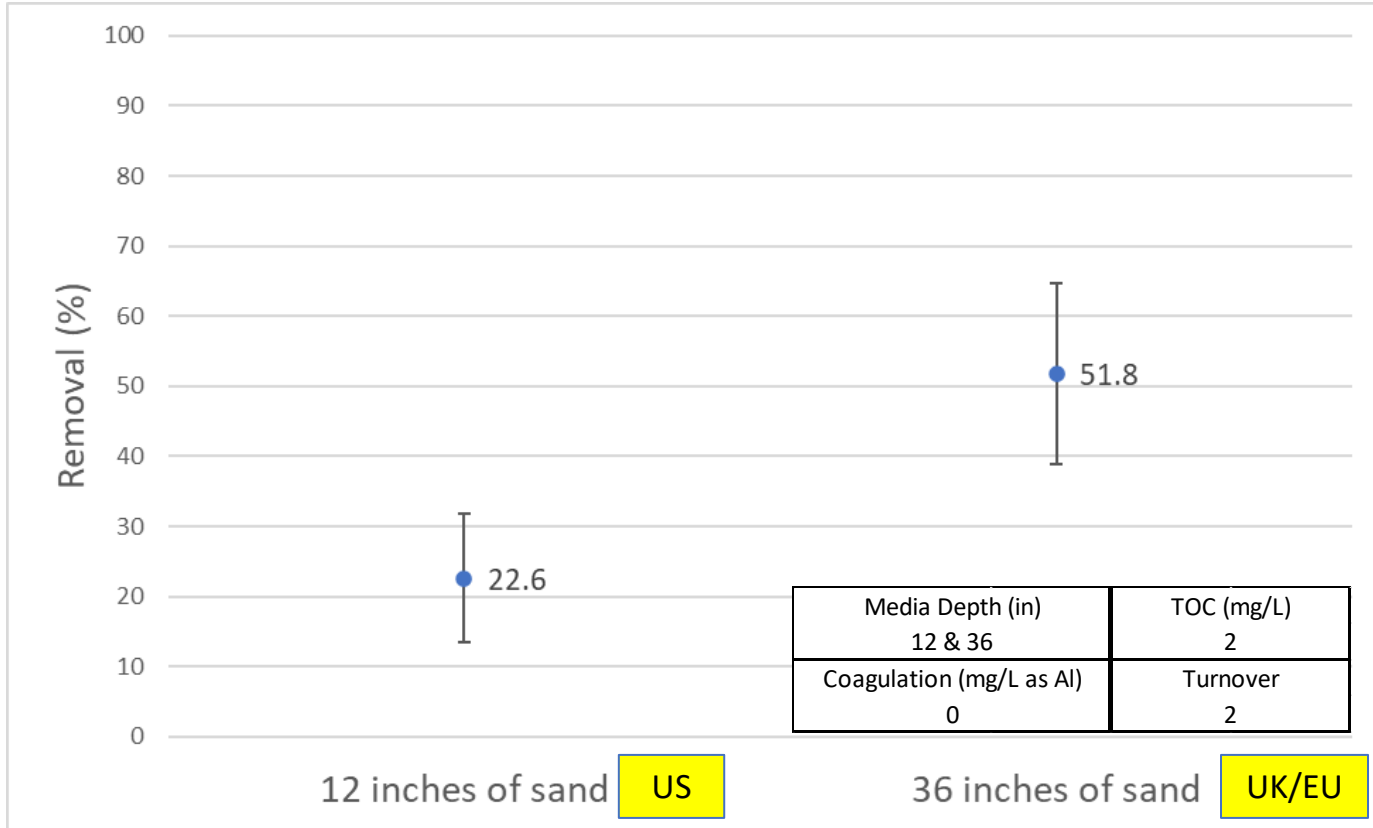
Effluent samples						
	time (min)	sample number	dose (mL)	count	#/mL	
	3	1	20	168	8.40	8.40
	3	2	20	195	9.75	
	3	3	20	141	7.05	
	7	1	20	185	9.25	8.42
	7	2	20	161	8.05	
	7	3	20	159	7.95	
	11	1	20	149	7.45	
	11	2	20	172	8.60	
	11	3	20	138	6.90	

2

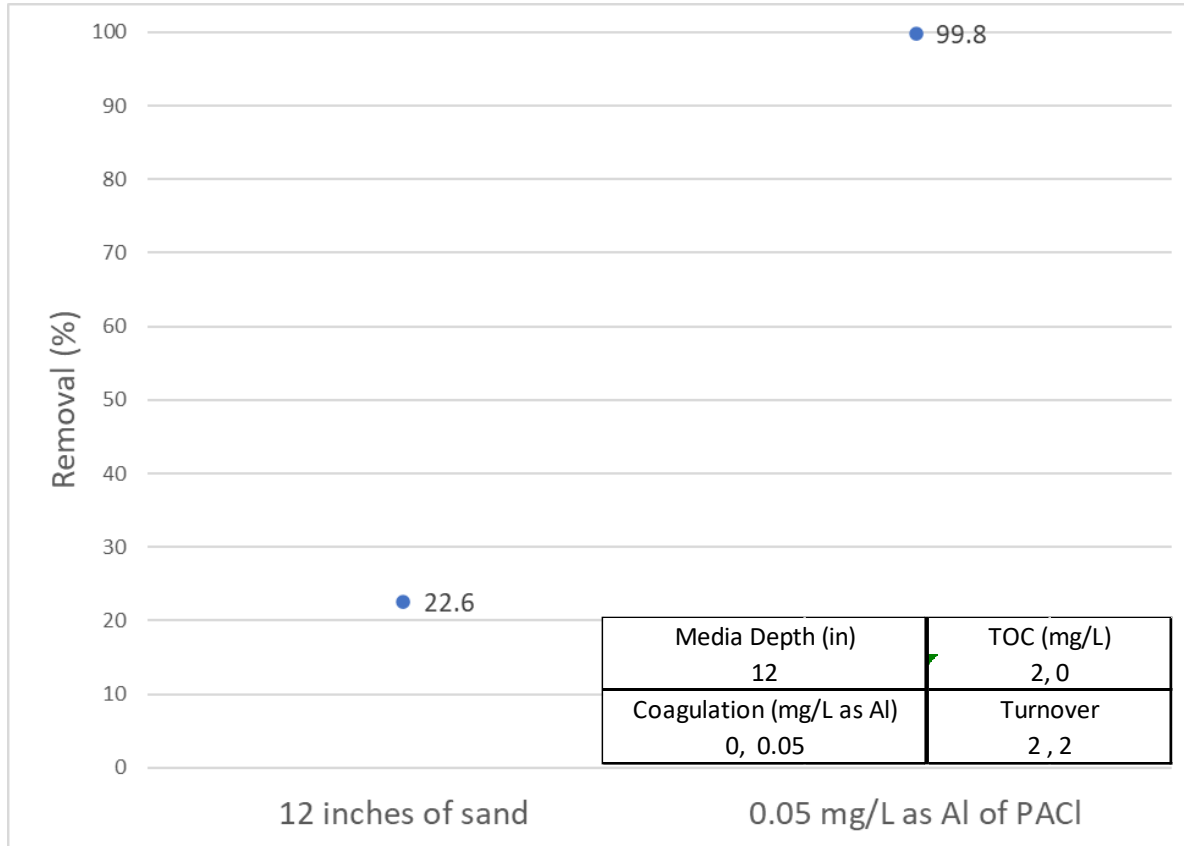
3

Average of Samples at Each Time					~95% Conf Int
time	% removal	Std. Dev.	LRV	Std. Dev.	2*SD
3	24.55	12.13	0.12	0.07	0.14
7	18.55	7.00	0.09	0.04	0.07
11	23.75	8.65	0.12	0.05	0.10
OVERALL AVERAGE:	22.28	8.70	0.11		

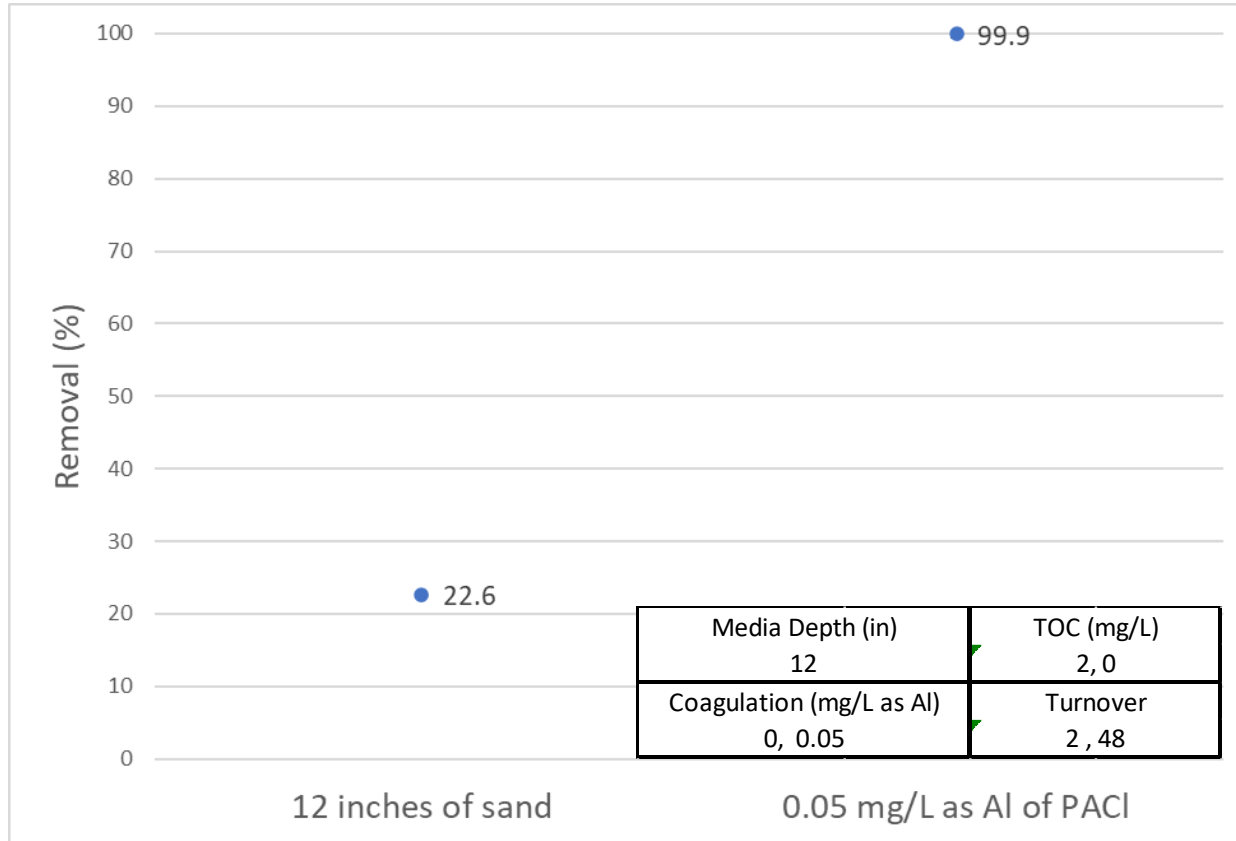
CONTROL: 12-inch & 36-inch Sand Filter @ 10 gpm/ft² (24 m/h), no coagulant



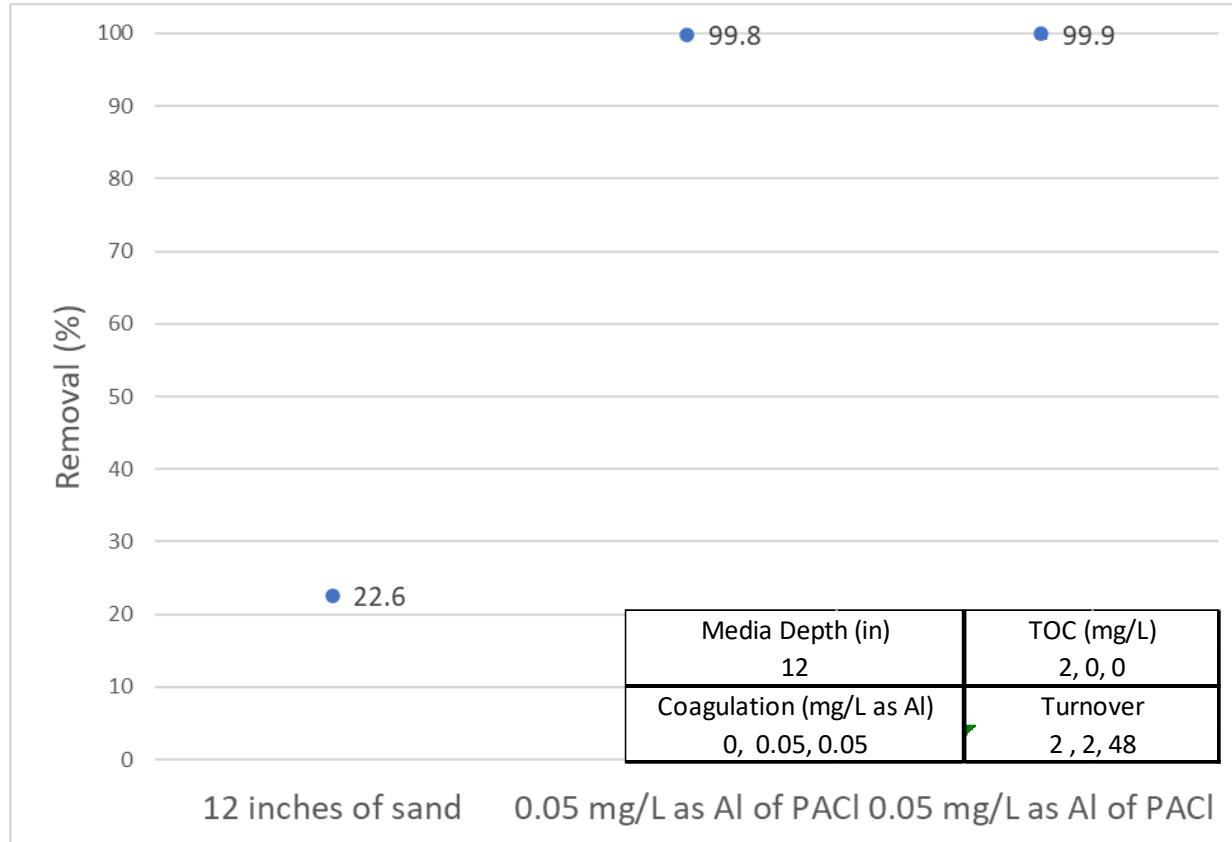
12-inch Coagulation Experiments (No TOC) ~2 hrs.



12-inch Coagulation Experiments (No TOC) ~48 hrs.



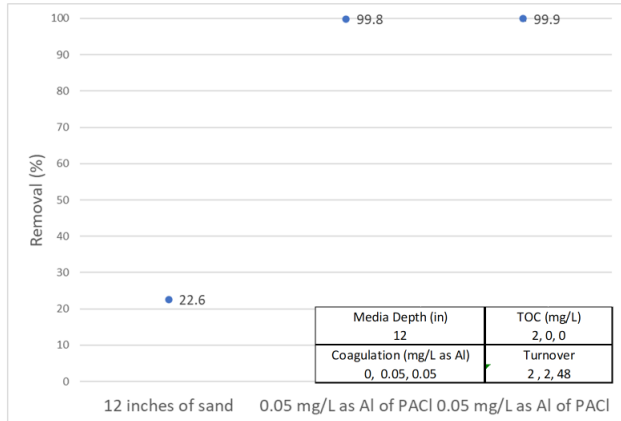
12-inch Coagulation Experiments (No TOC)



12-inch Coagulation Experiments (No TOC)

- This confirms prior research findings...
- ... findings that also did not include bather load.

12-inch Coagulation Experiments (No TOC)



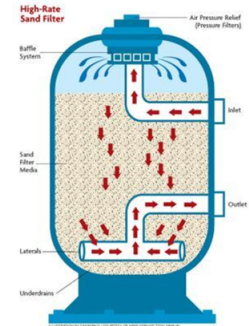
Prior Research

Sand Filtration (US)

- Shown to be ineffective with only 0.19 Log (36%) removal of *Cryptosporidium* sized particles (Amburgey 2012)

Sand Filtration + Coagulation (UK)

- Sand filtration with coagulation using poly aluminum chloride (PACl) can significantly increase the removal of Crypto-sized particles. With coagulation, greater than 99% removals were achieved (Croll et al. 2007, Amburgey et al. 2012, Lu & Amburgey 2016)



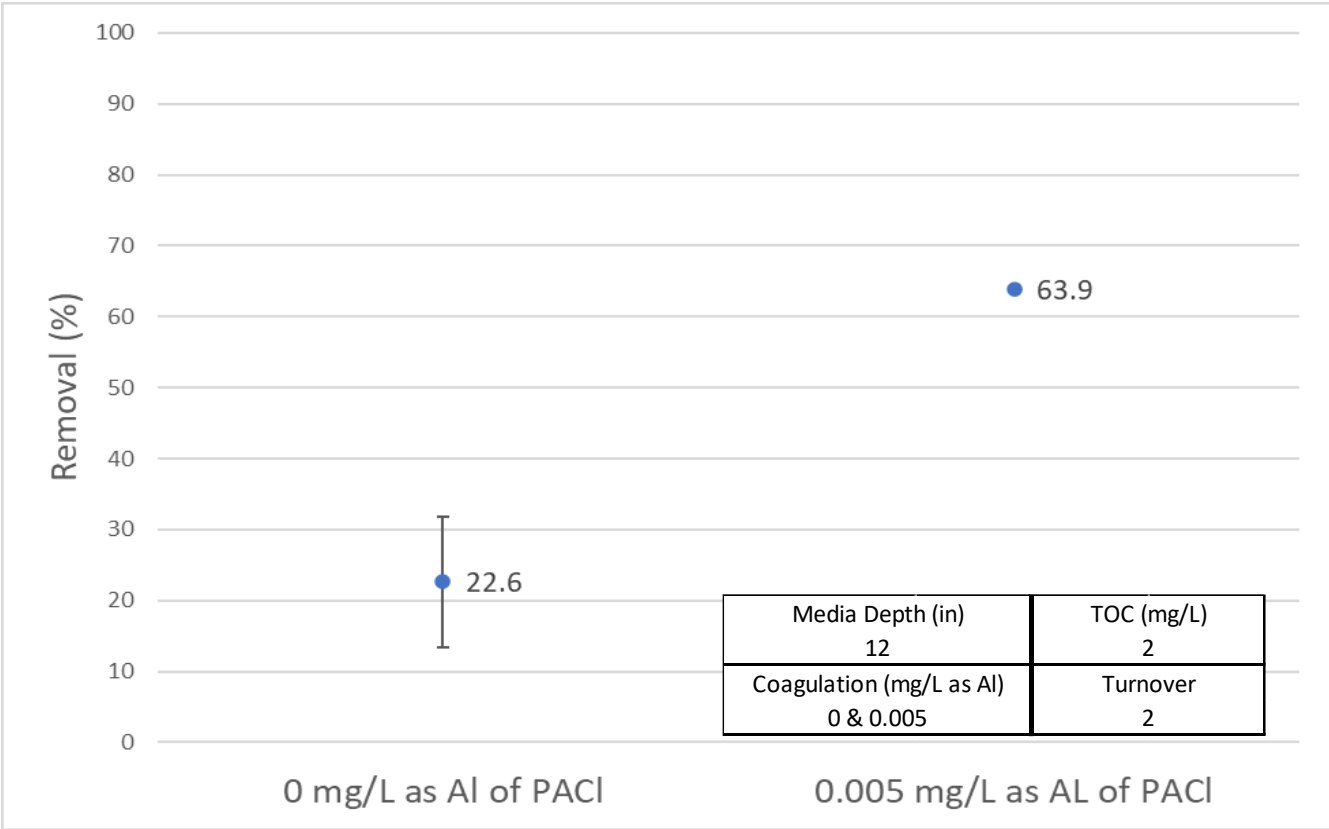
Source: Rob Duran, 2018, The Workhorse
https://www.poolpanes.com/new-to/design-construction/the-workhorse_0

Problem solved!

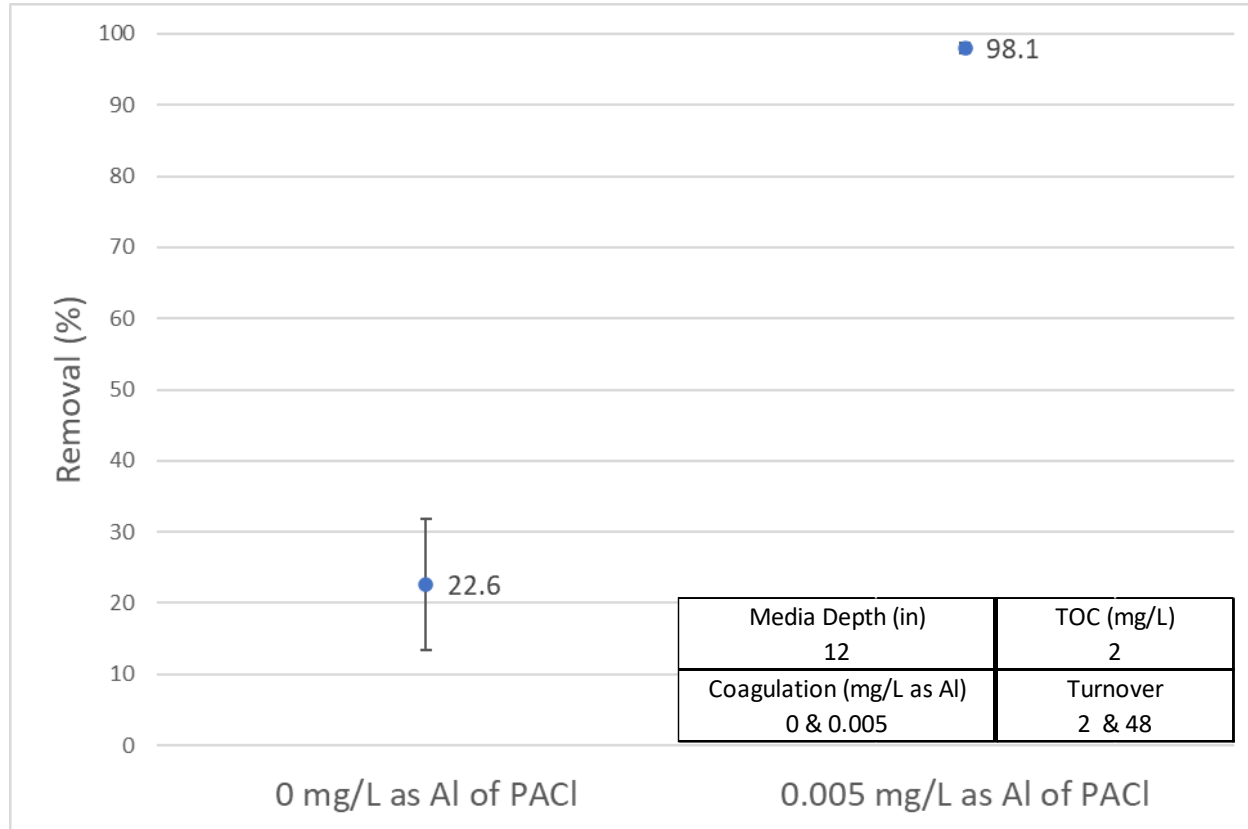
- Any questions?



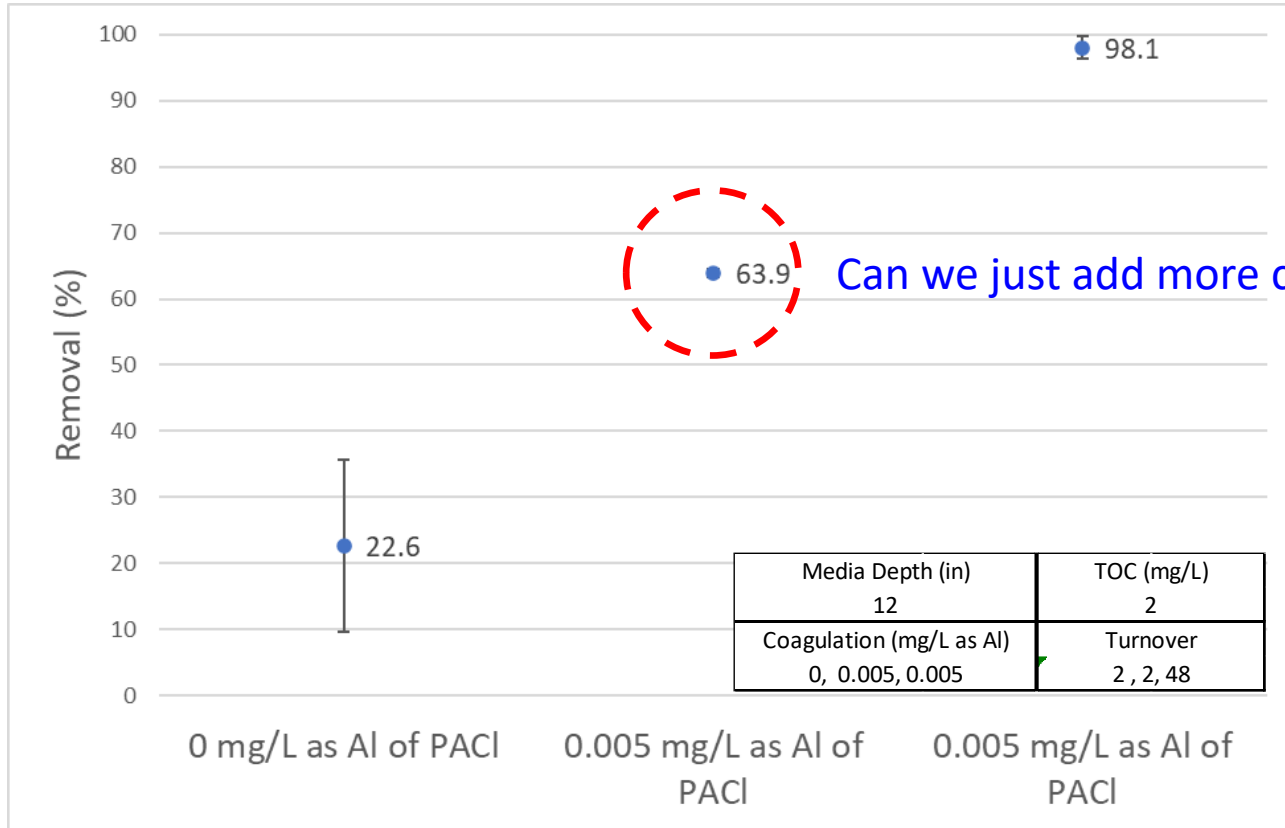
12-inch Coagulation Experiments (+ TOC) ~2 hrs.



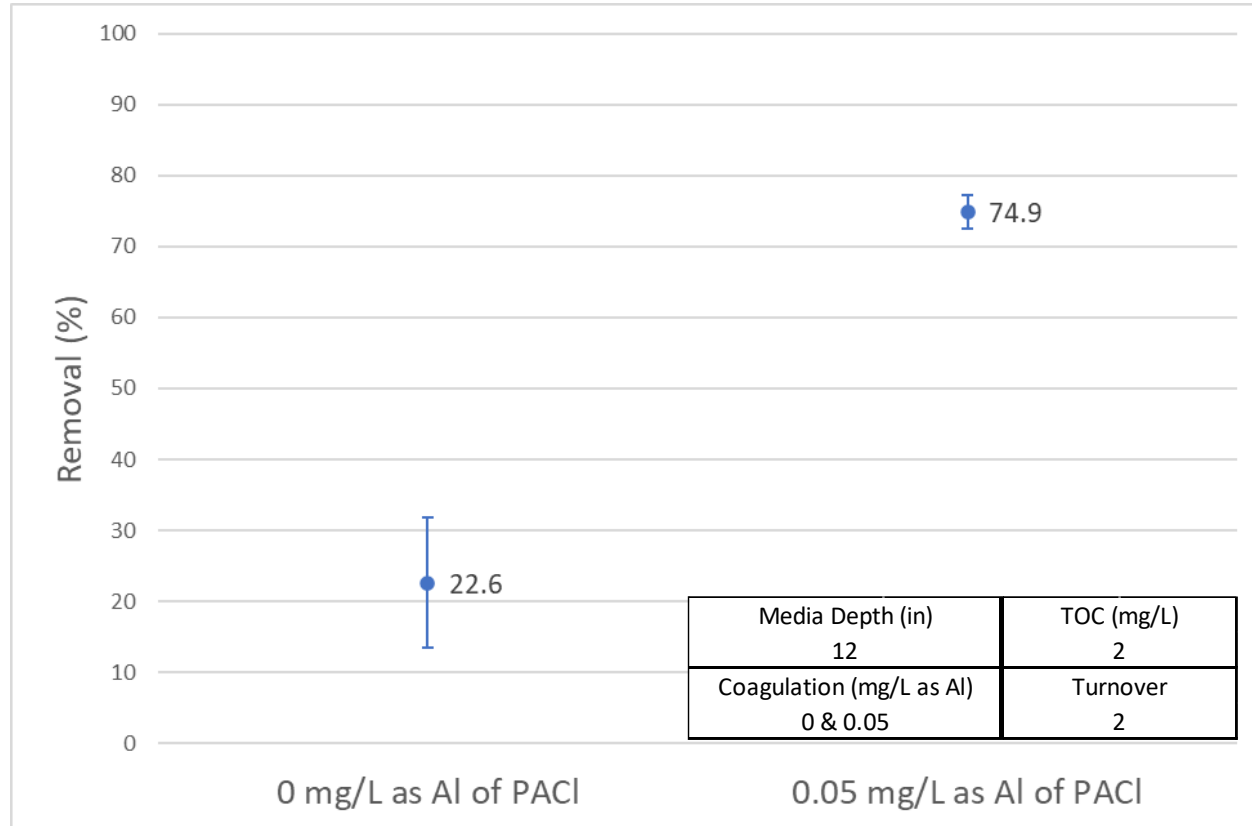
12-inch Coagulation Experiments (+ TOC) ~48 hrs.



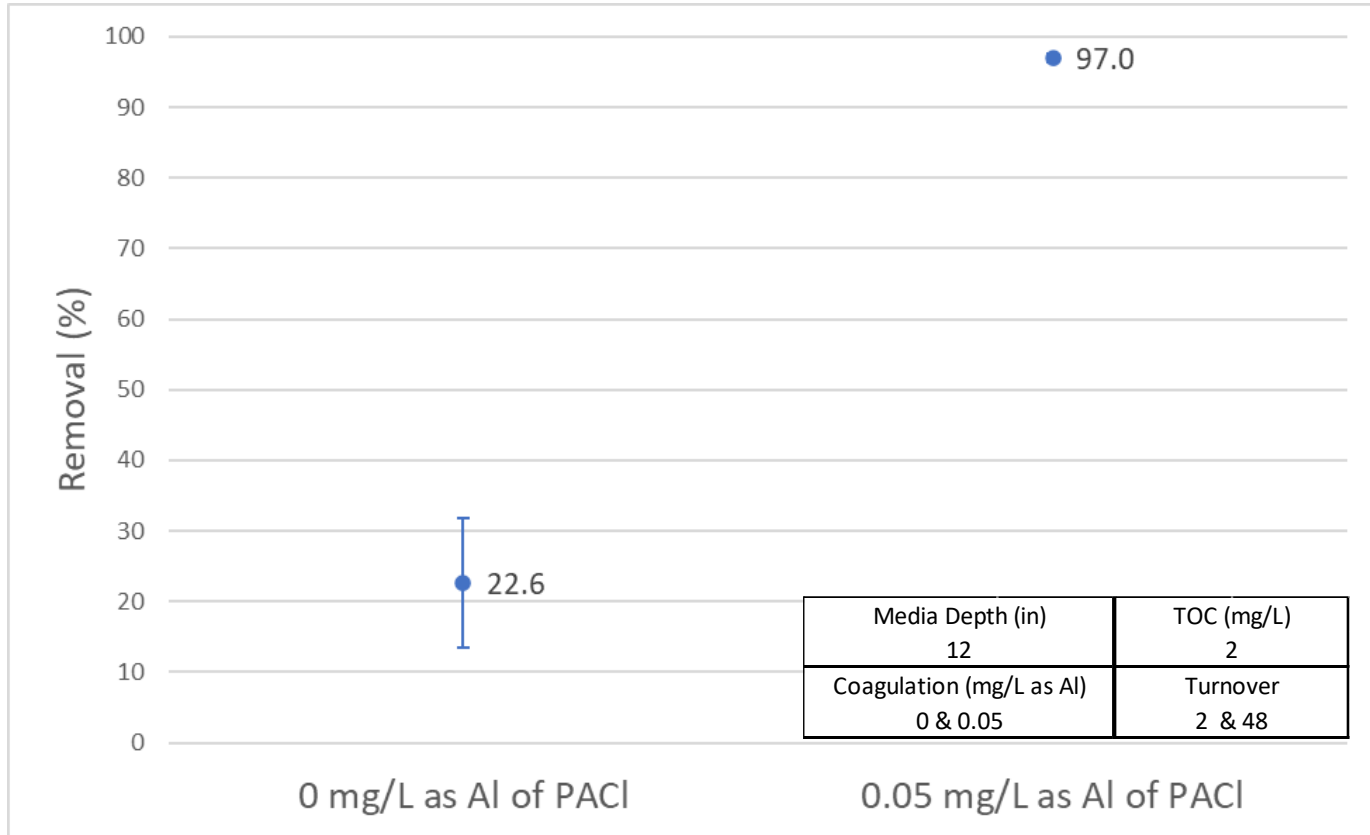
12-inch Coagulation Experiments (+ TOC)



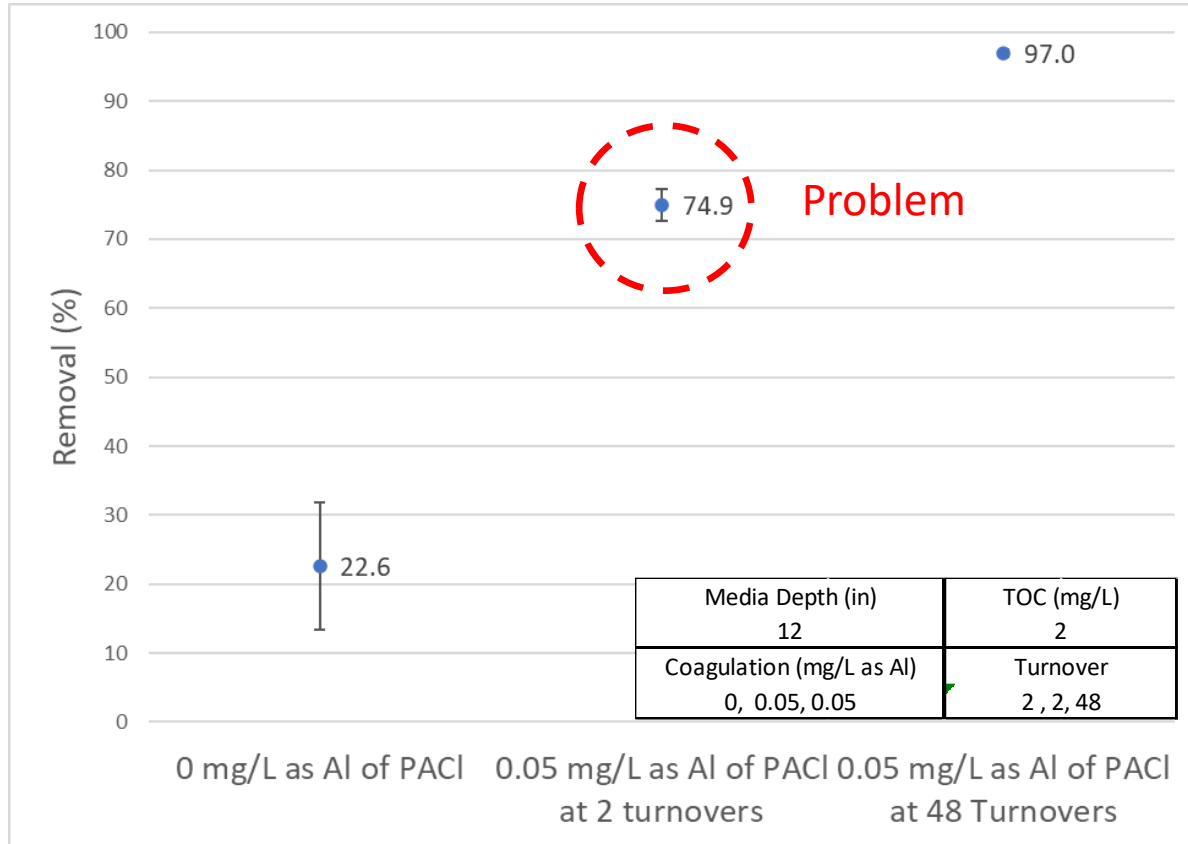
12-inch 10 x Coagulation Experiments (+ TOC) ~2 hrs.



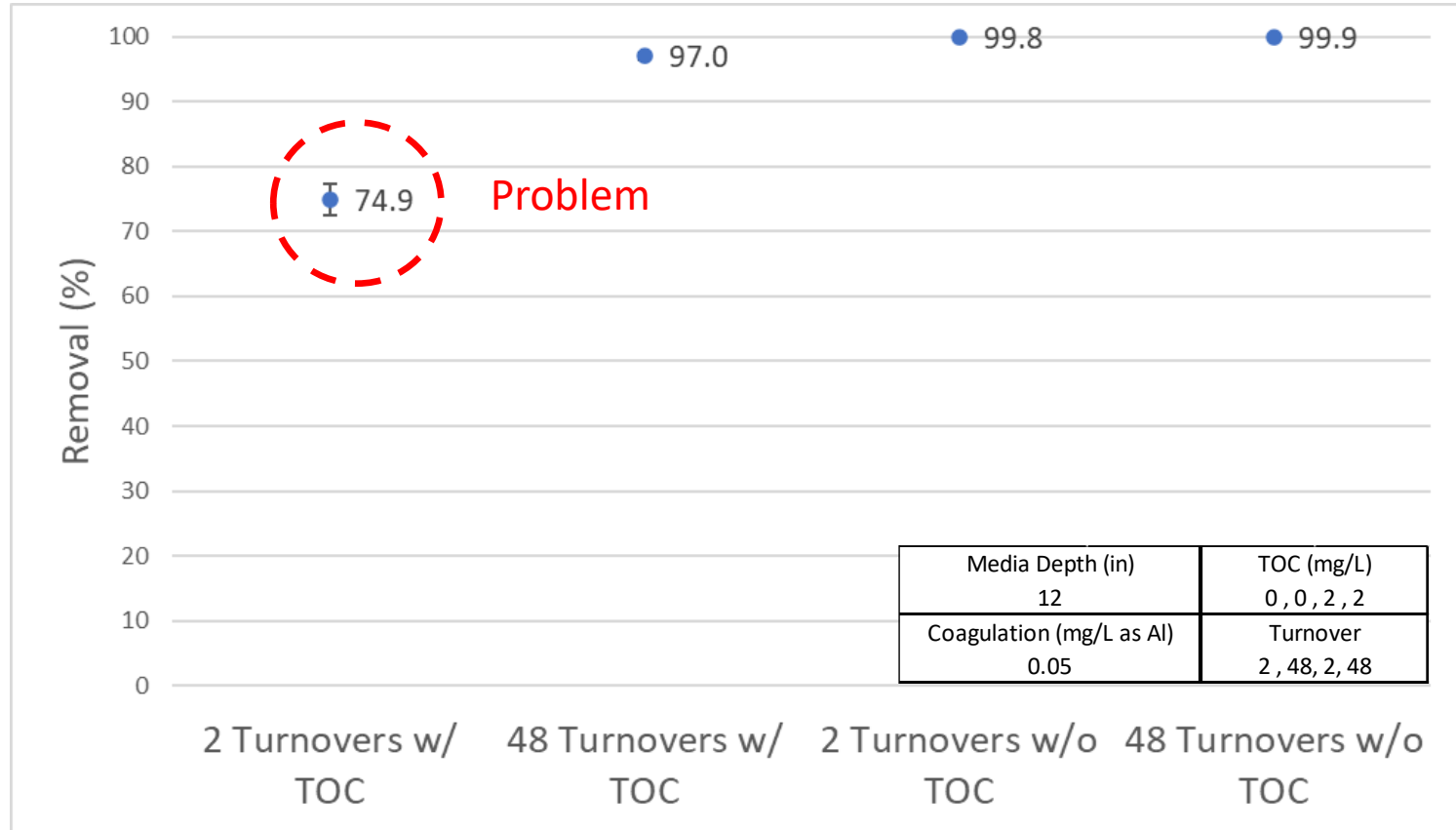
12-inch 10 x Coagulation Experiments (+ TOC) ~48 hrs.



12-inch 10 x Coagulation Experiments (+ TOC)



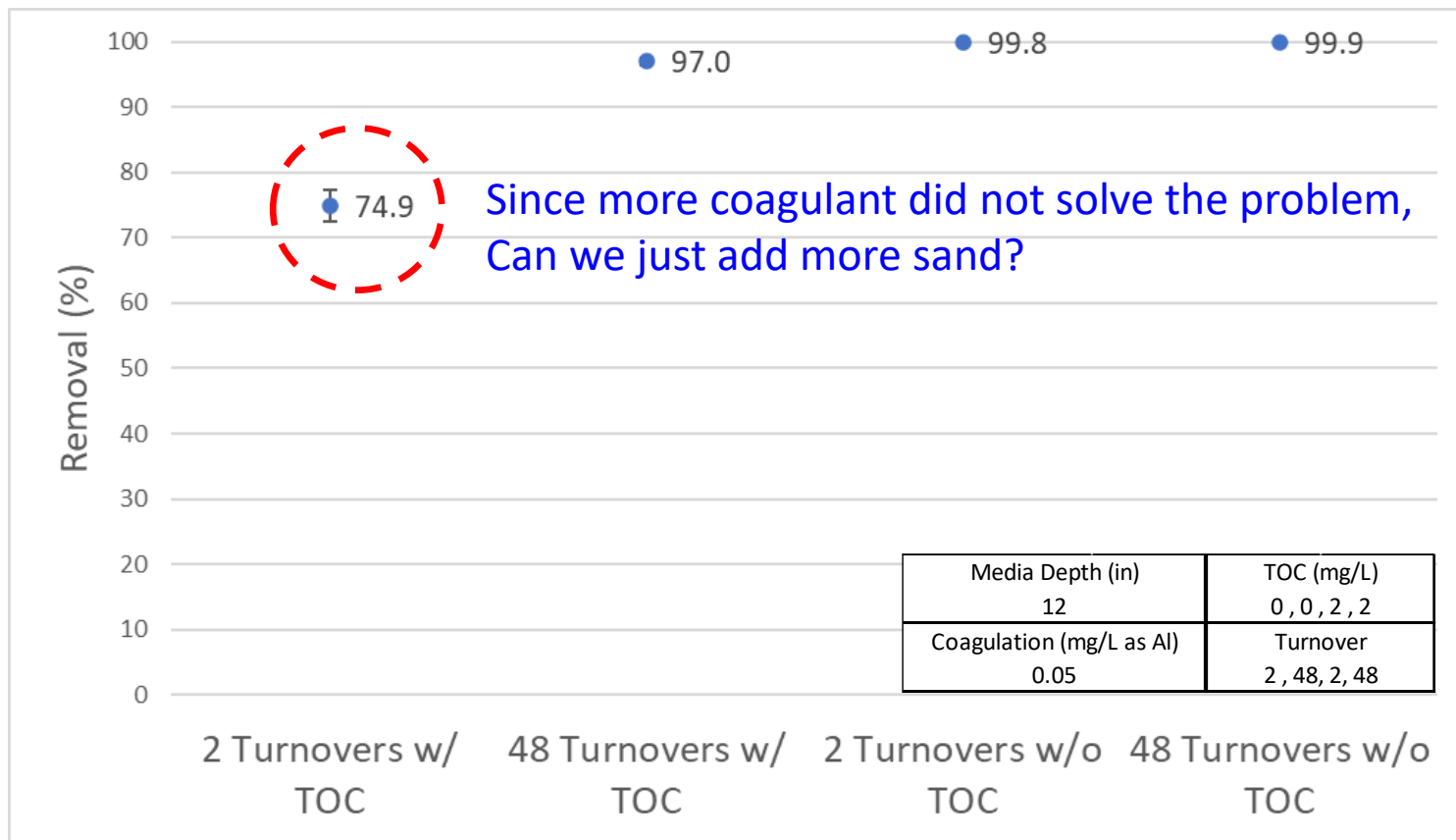
Even at 10 x Coagulation, Bather load is a problem



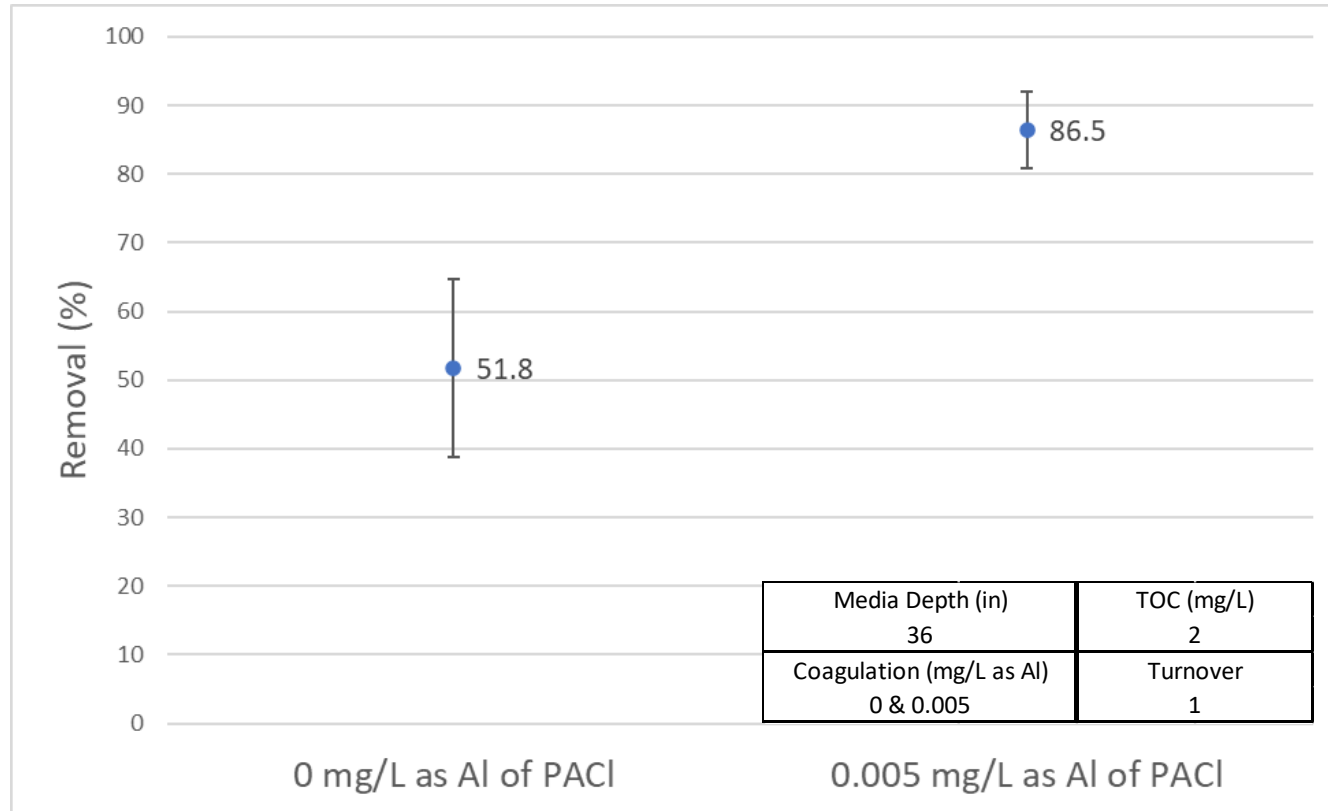
Bather load statistics

- No TOC experiments at both times outperformed +TOC experiments
 - 2 Turnovers
 - P-value 3.41×10^{-6}
 - 48 turnovers
 - P-value 2.35×10^{-6}

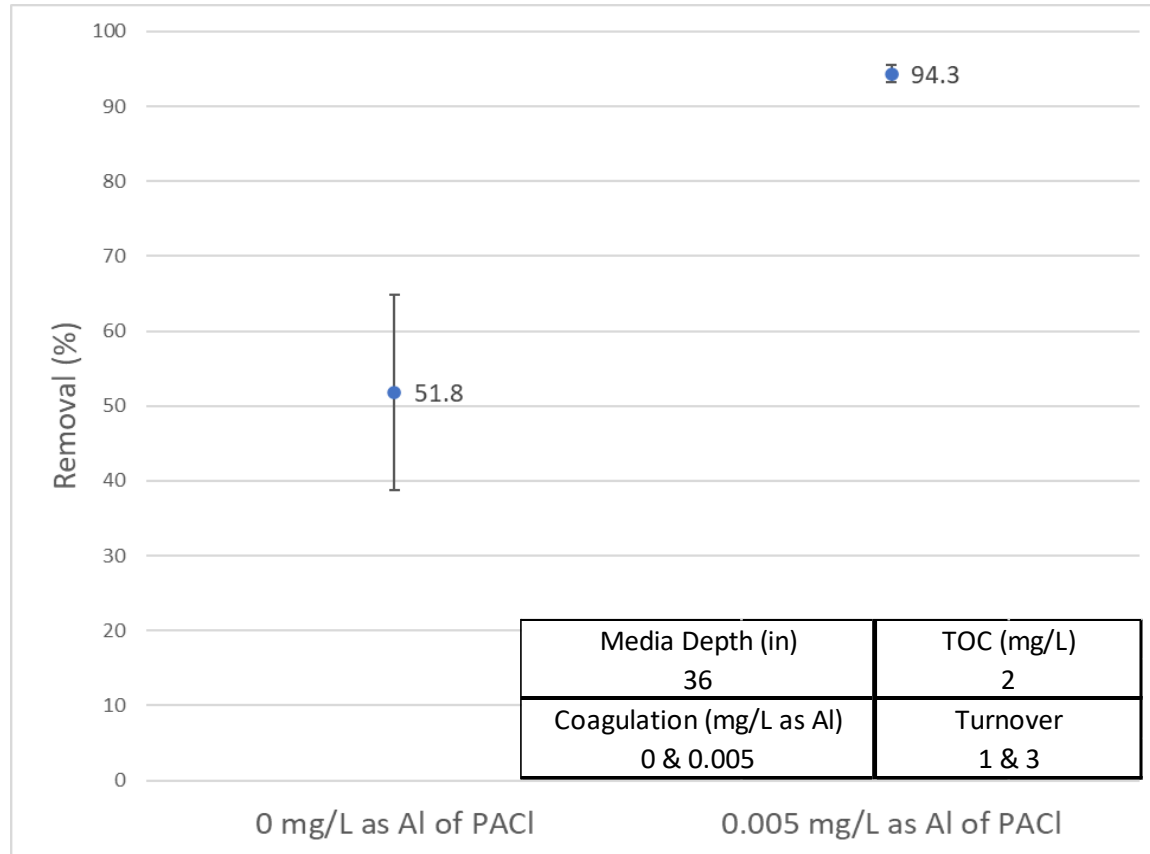
Even at 10 x Coagulation, Bather load is a problem



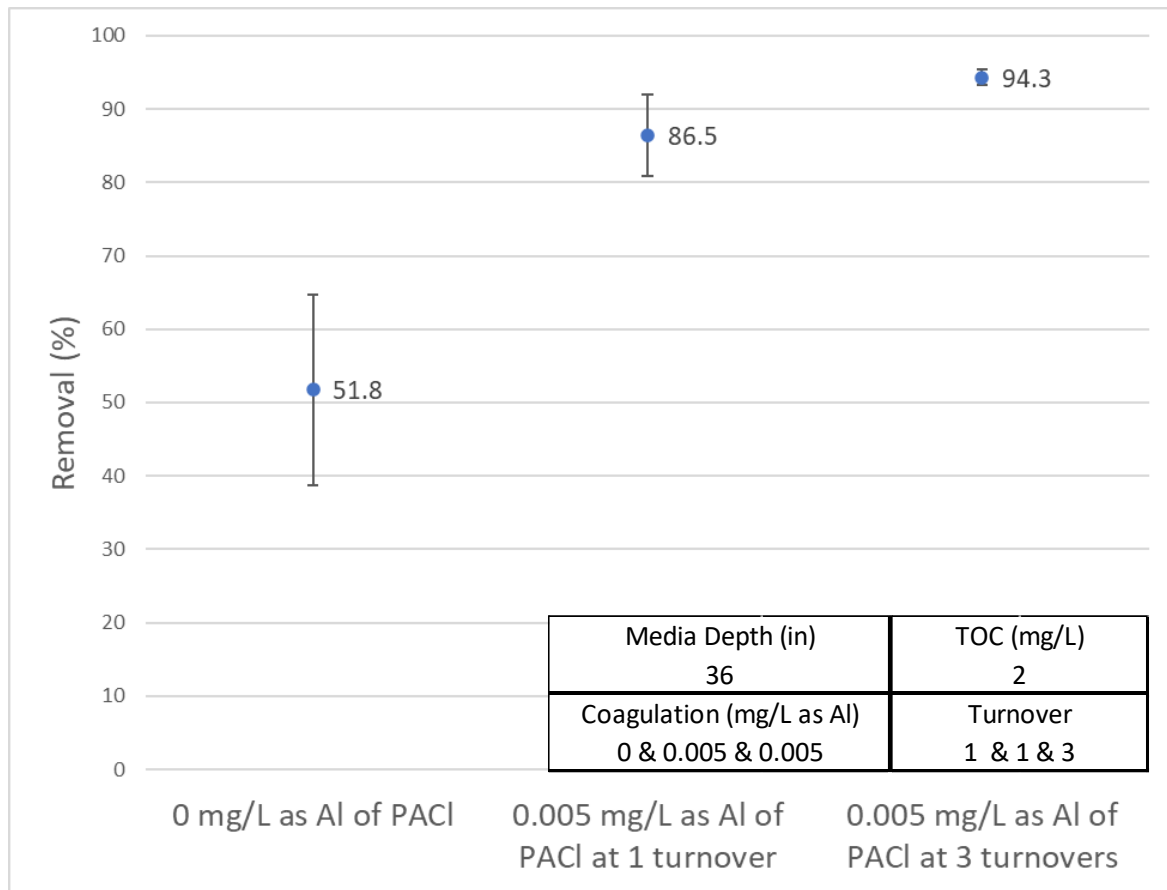
36-inch Coagulation Experiments (+ TOC) ~ 1 hr.



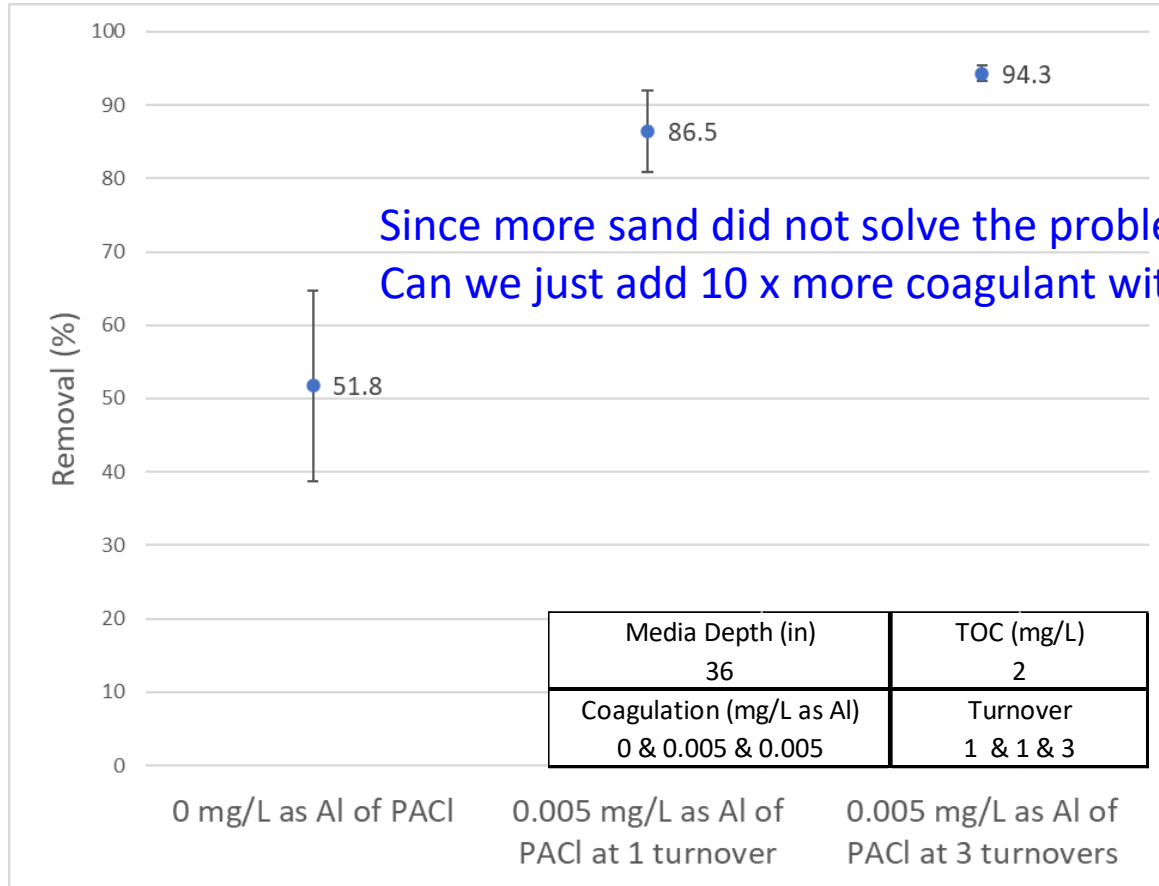
36-inch Coagulation Experiments (+ TOC) ~ 3 hrs.



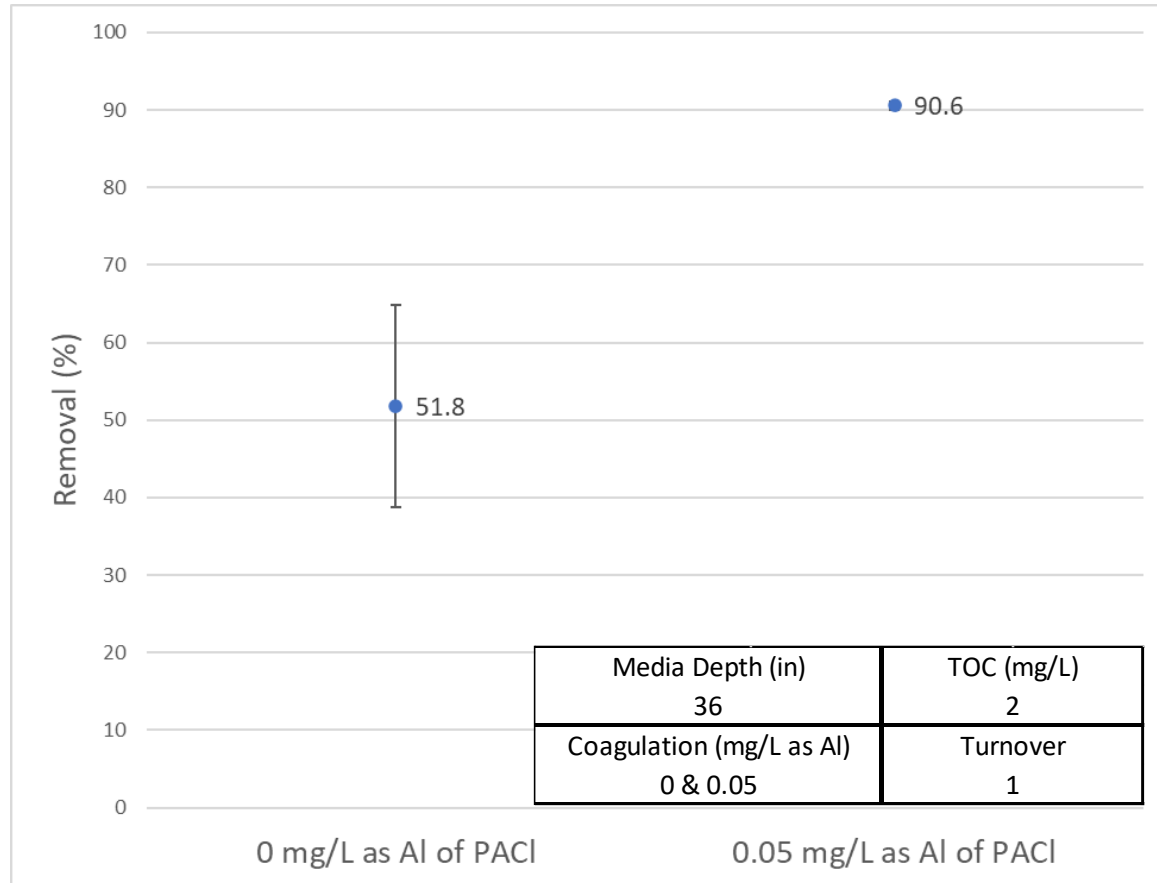
36-inch Coagulation Experiments (+ TOC)



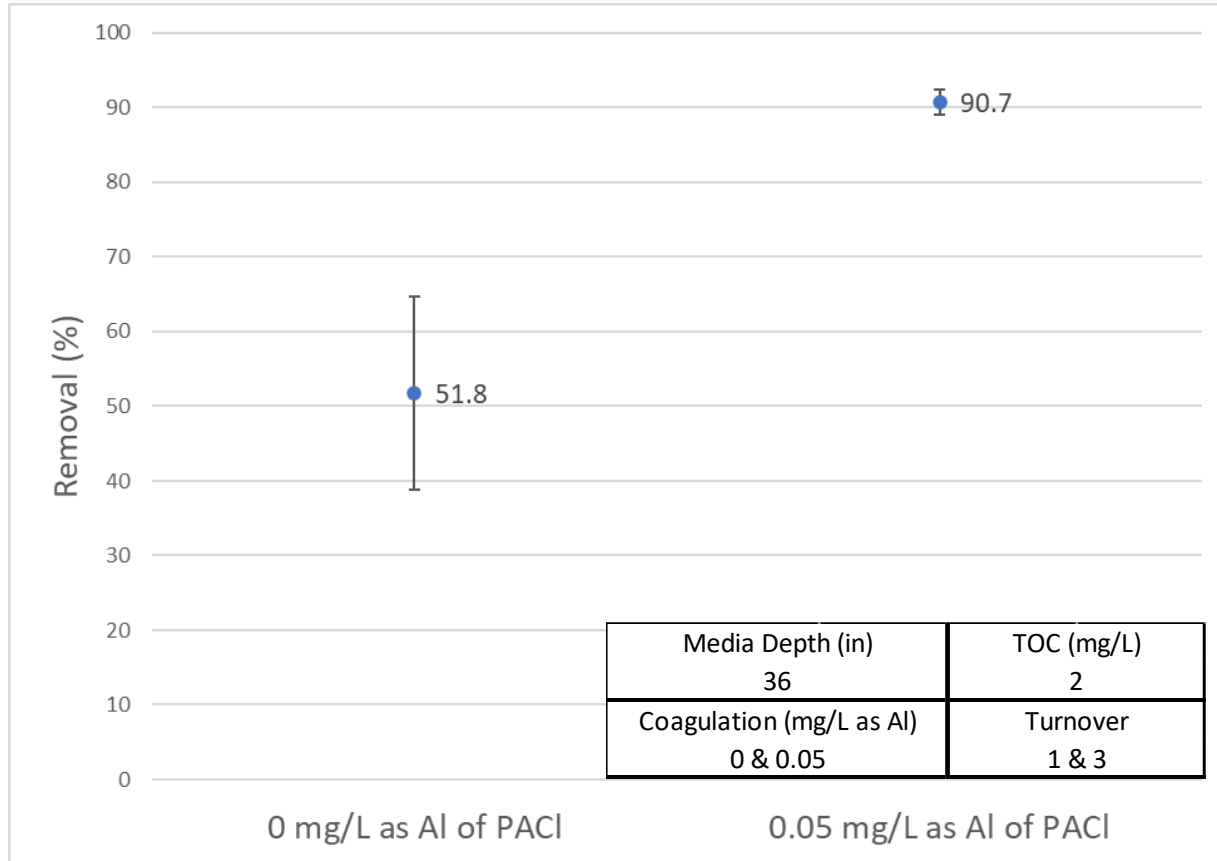
36-inch Coagulation Experiments (+ TOC)



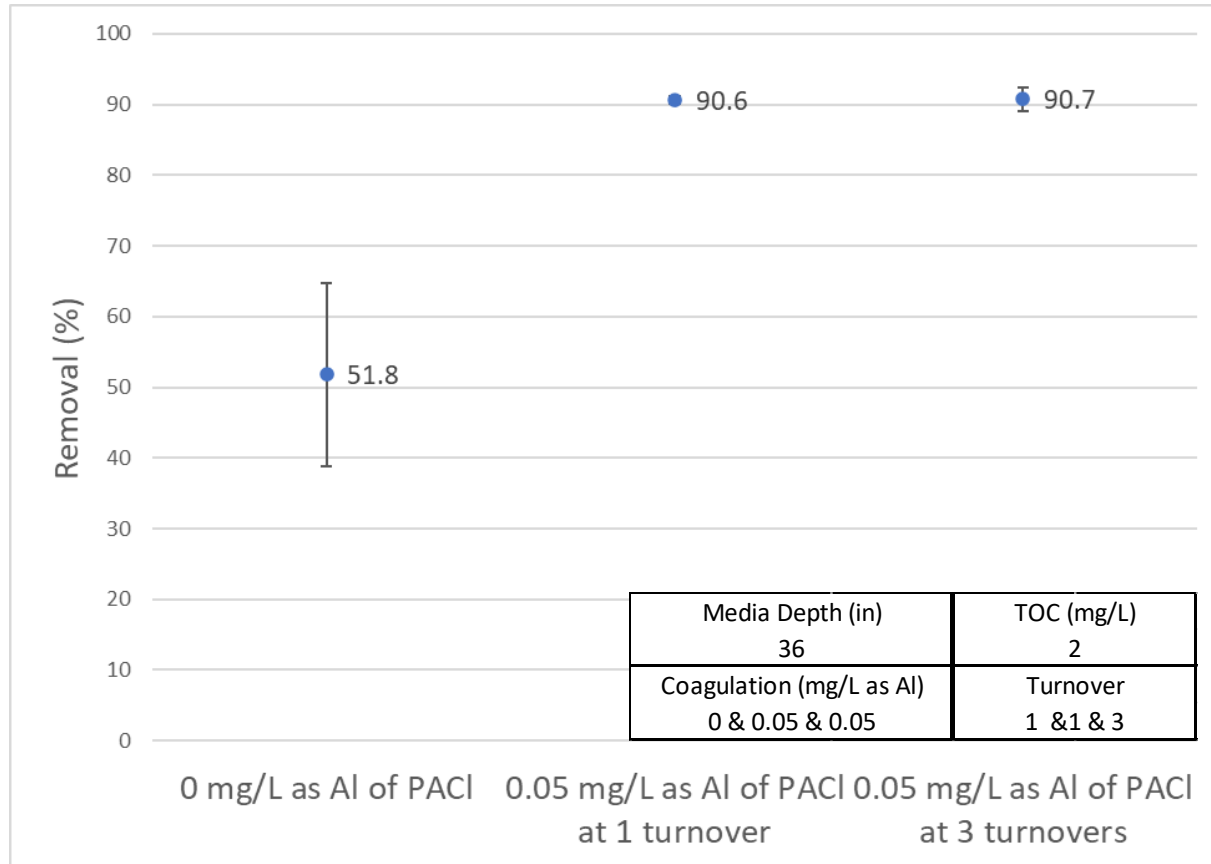
36-inch 10 x Coagulation Experiments (+ TOC) ~ 1 hr.



36-inch 10 x Coagulation Experiments (+ TOC) ~ 3 hr.

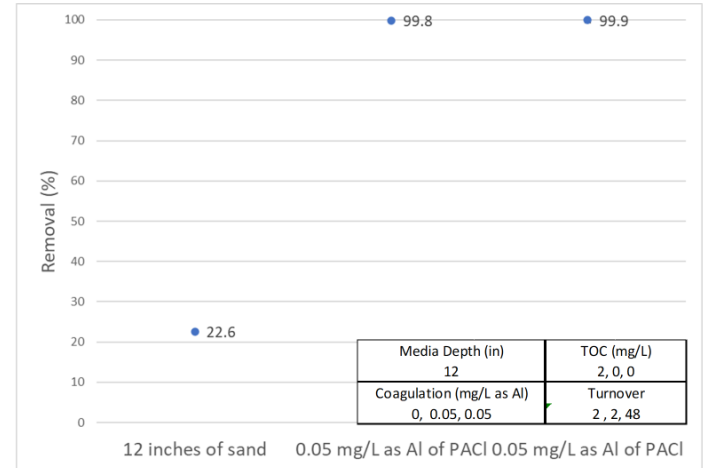
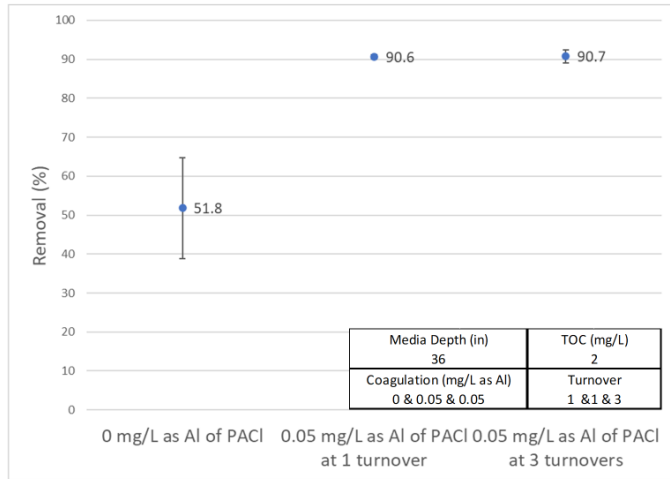


36-inch 10 x Coagulation Experiments (+ TOC)



Even with 36-inches of Sand **AND** 10 x Coagulation, Results with (+ TOC) are worse by nearly 2 log!

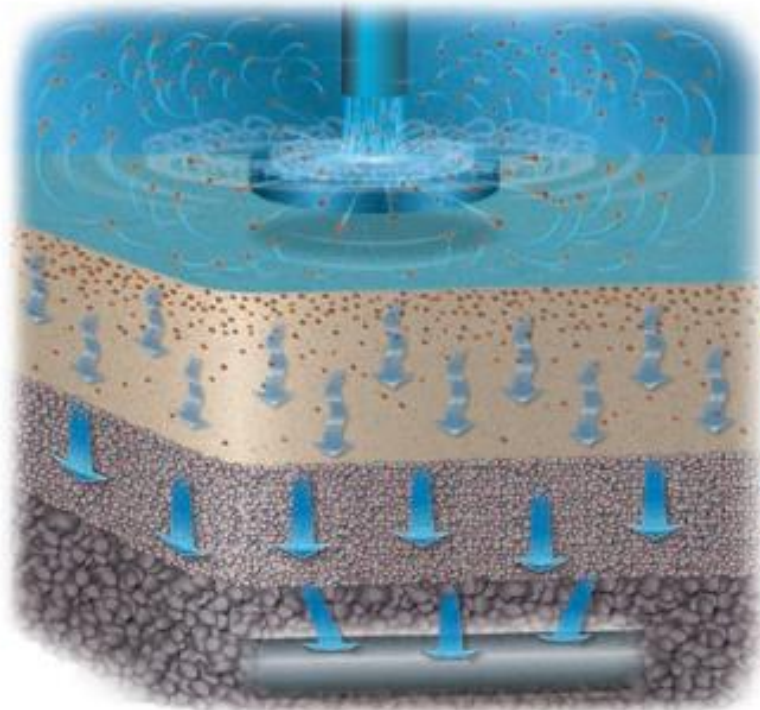
36-inch 10 x Coagulation Experiments (+ TOC) 12-inch Coagulation Experiments (No TOC)



So, adding bather load (bathers) decreases particle/pathogen removal!

Vortisand Filter: (microsand/vortex flow)

VORTISAND C-SERIES FILTER: AN INSIDE LOOK



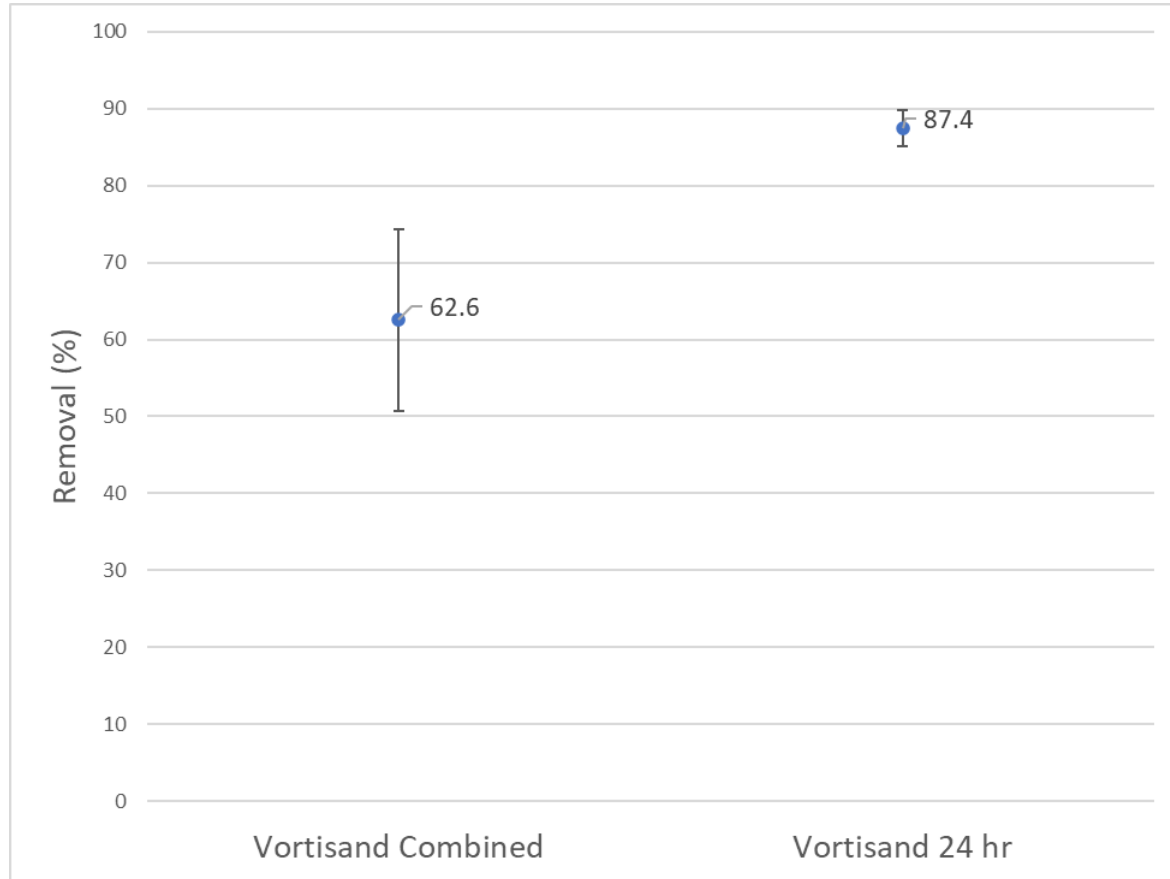
Cross-Flow: VortiJet injector induces a cross-flow pattern across surface of media. Large particles are kept in suspension which prevent media surface blinding.

Microsand: Small particles penetrate the fine microsand media bed where they are trapped within the small voids between the media.

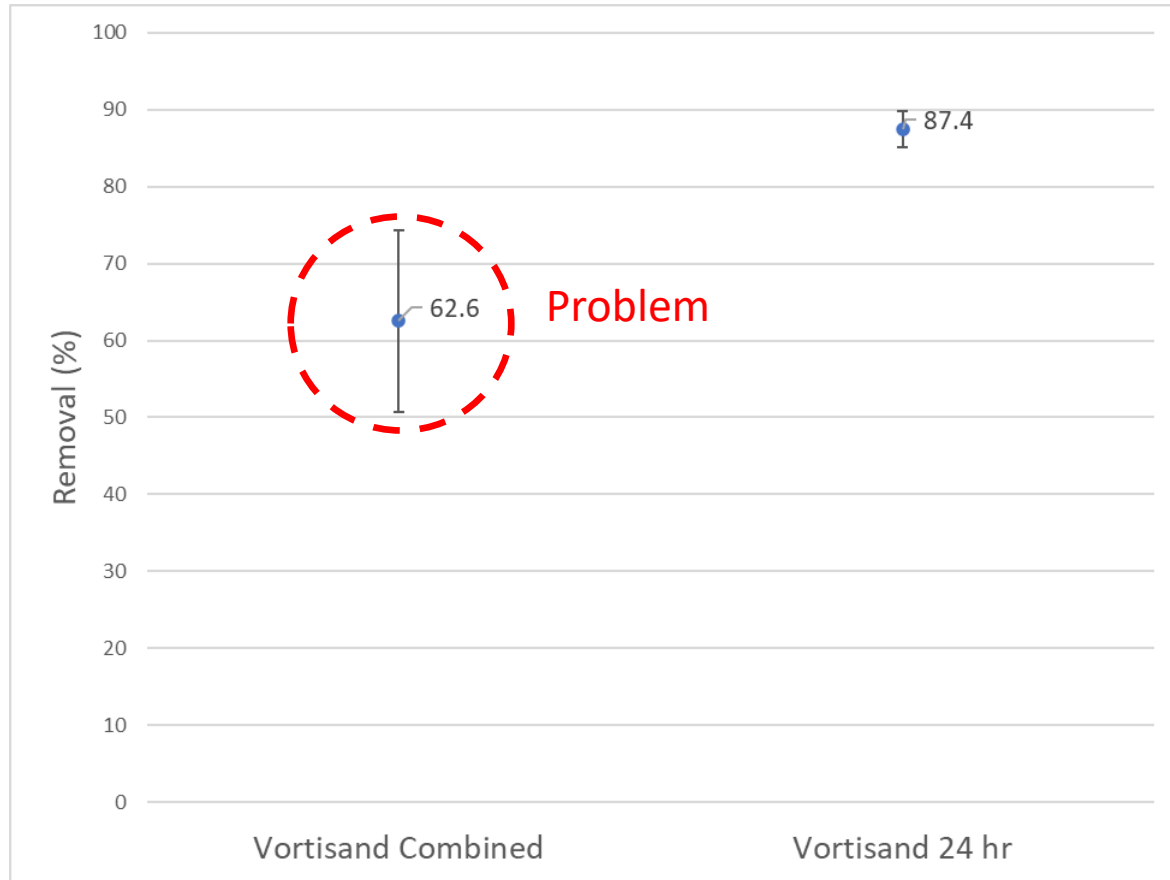
Support Structure: Larger media is used to act as a support structure for the microsand. These layers do not perform filtration.

Underdrain: Filtered water flows through the support layers and out through the wedge wire underdrain.

Vortisand Experiments

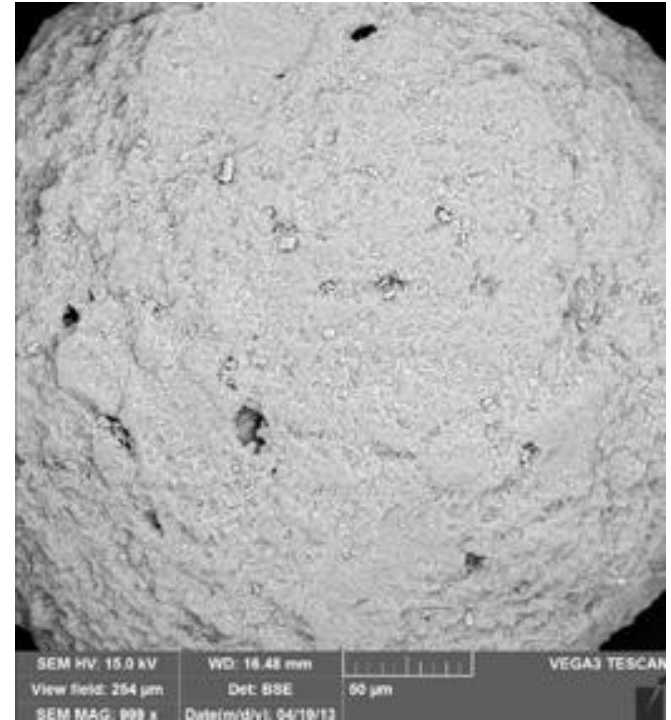
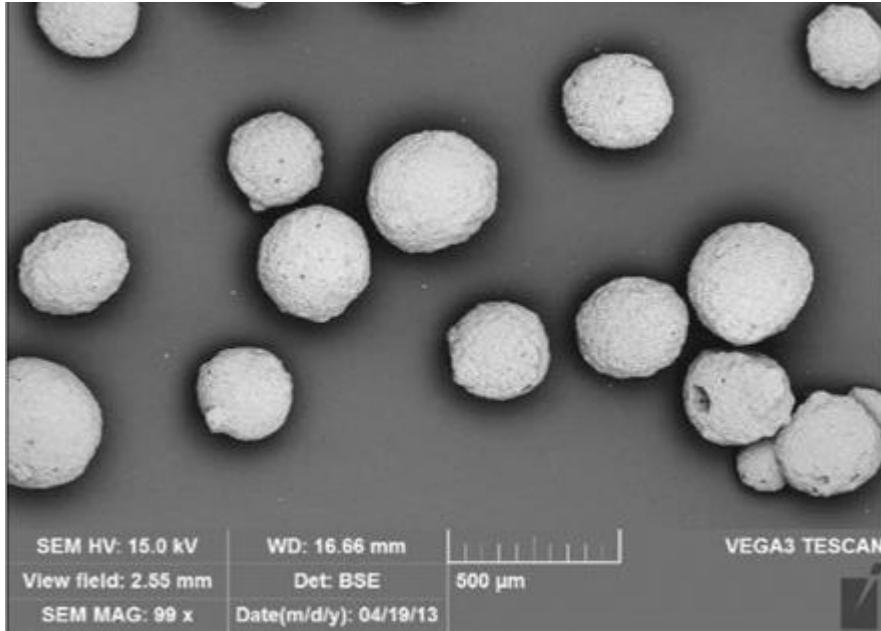


Vortisand Experiments

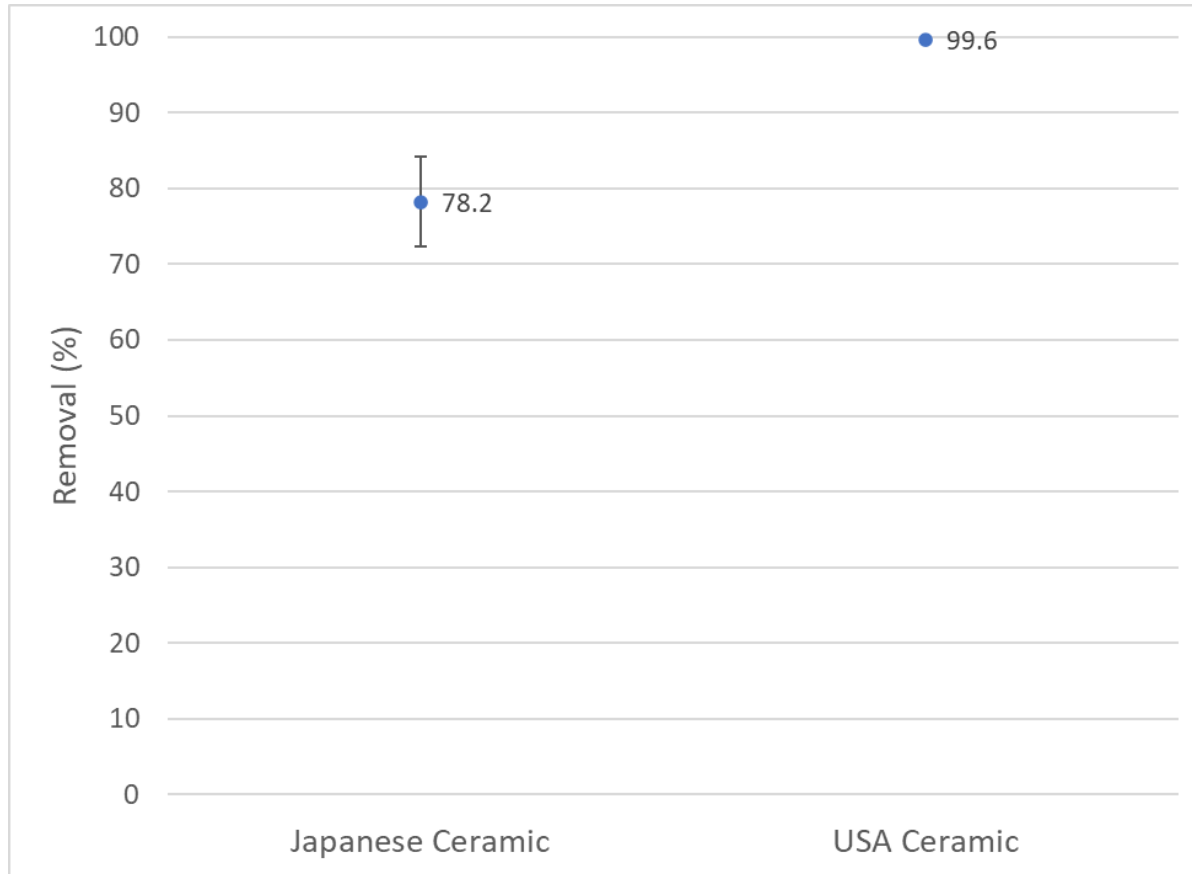


How about Ceramic filter media?

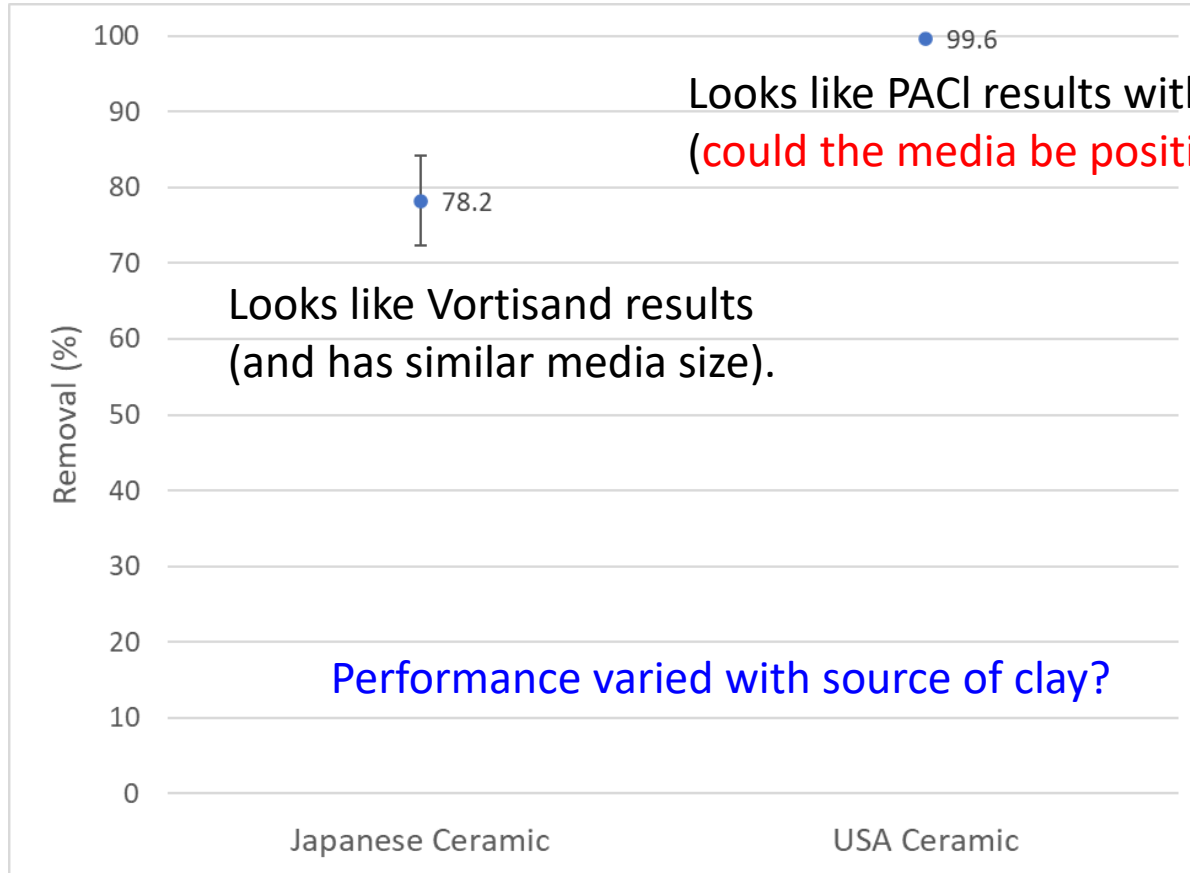
- 22-inches of Ceraflow-70 (effective size 0.15 – 0.25 mm)
- Source: Wateropolis, Newbury, OH, USA



22-inch Ceramic Experiments



22-inch Ceramic Experiments

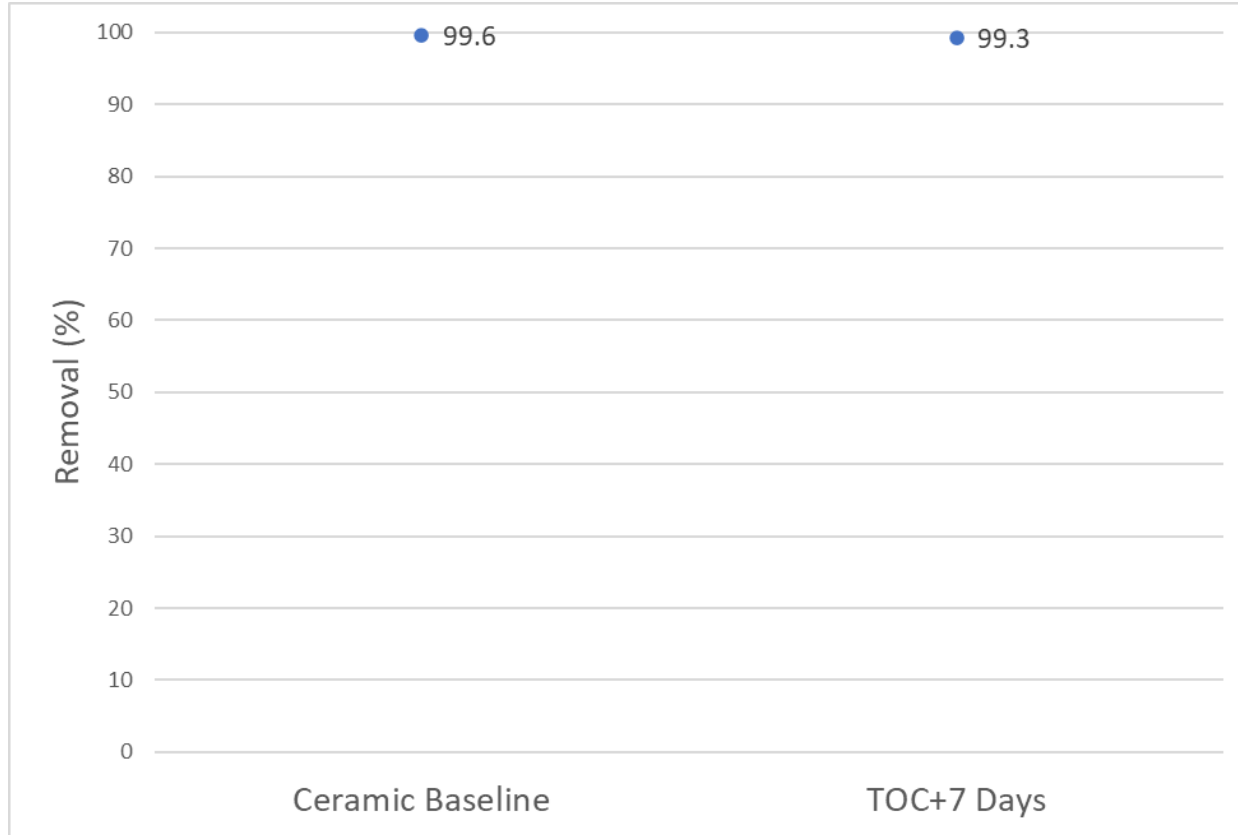


Looks like PACI results without coagulant
(could the media be positively charged?)

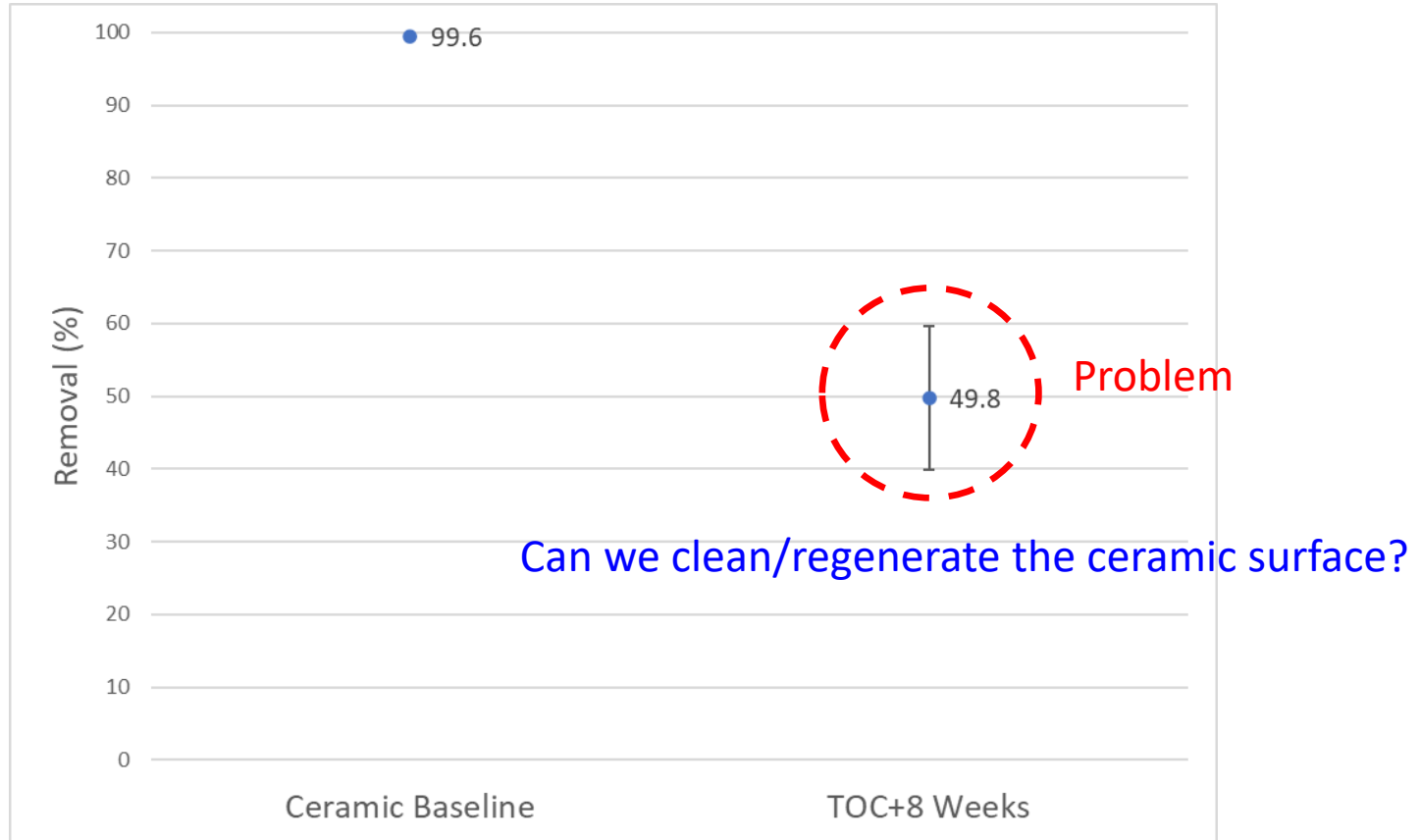
Looks like Vortisand results
(and has similar media size).

Performance varied with source of clay?

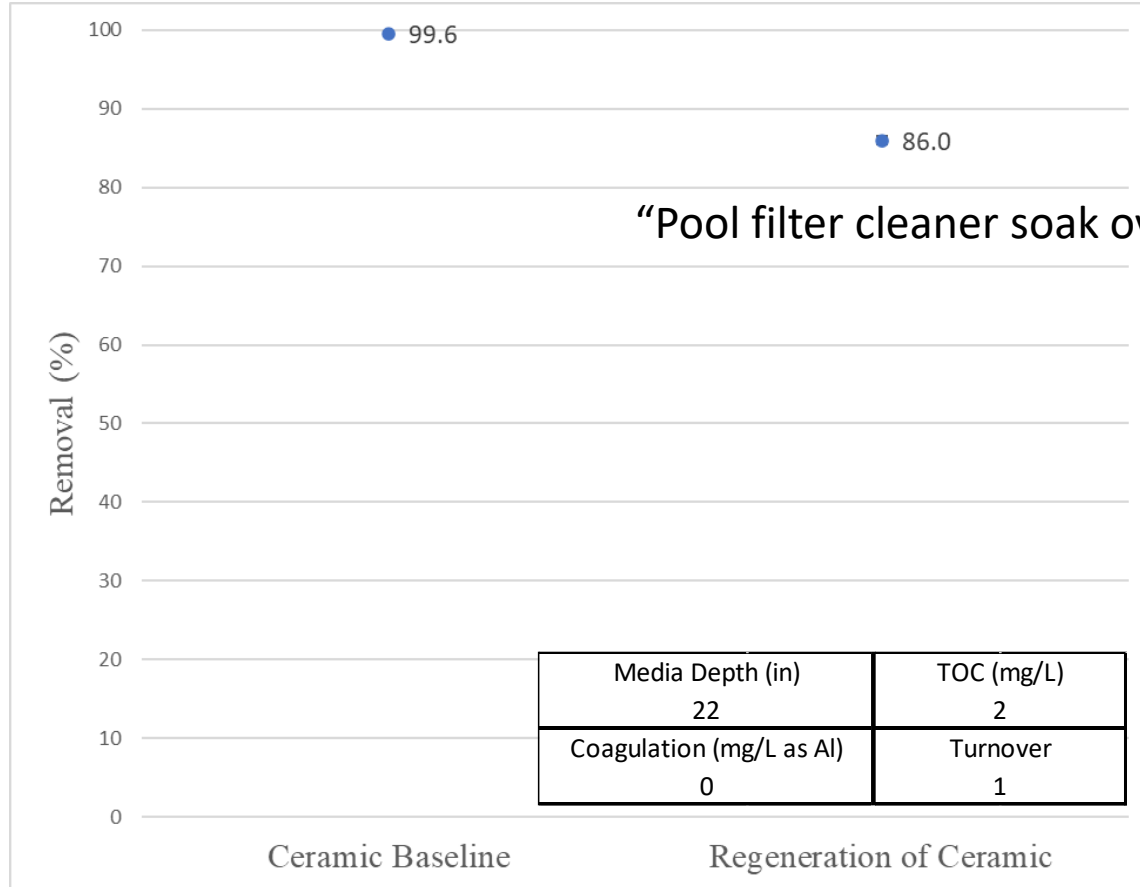
22-inch Ceramic Experiments (+7 days TOC)



22-inch Ceramic Experiments (+56 days TOC)

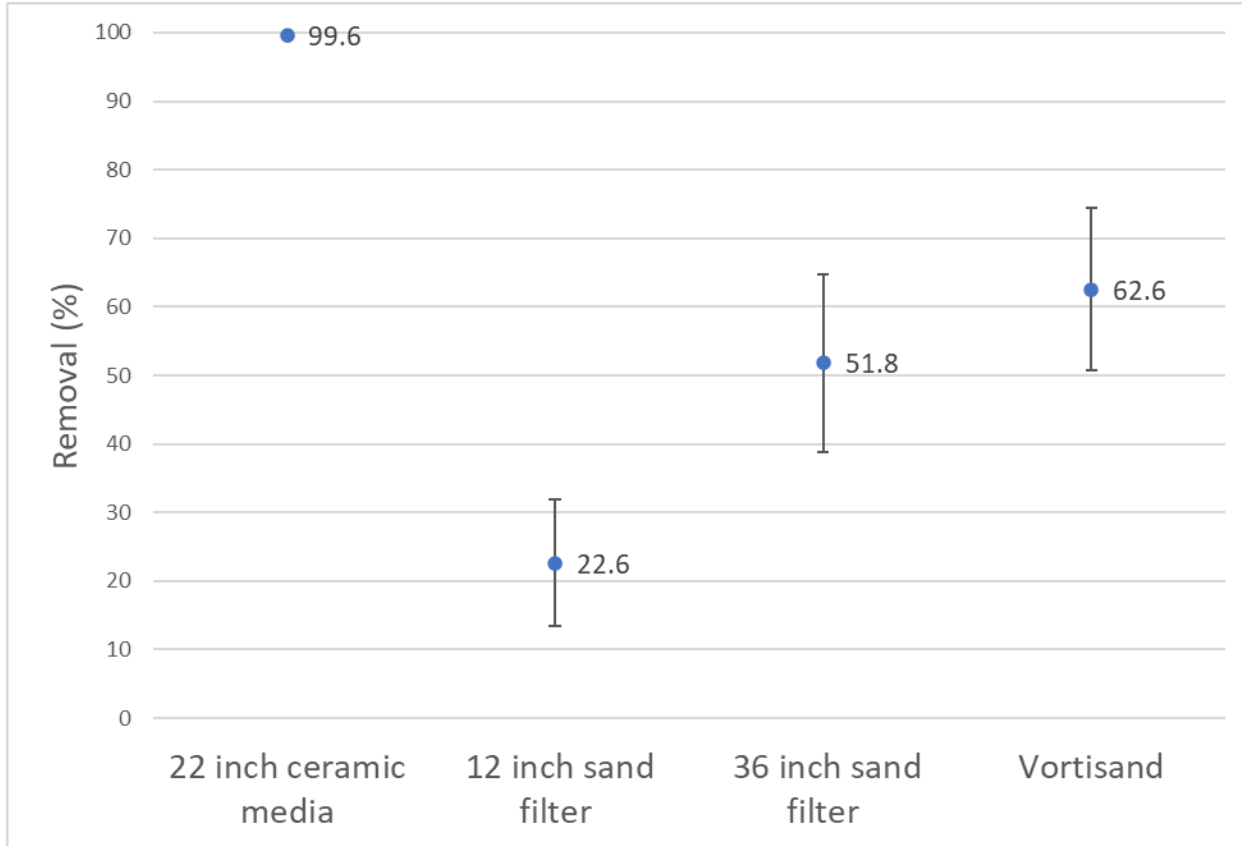


Bench-scale Ceramic “regen” Experiments

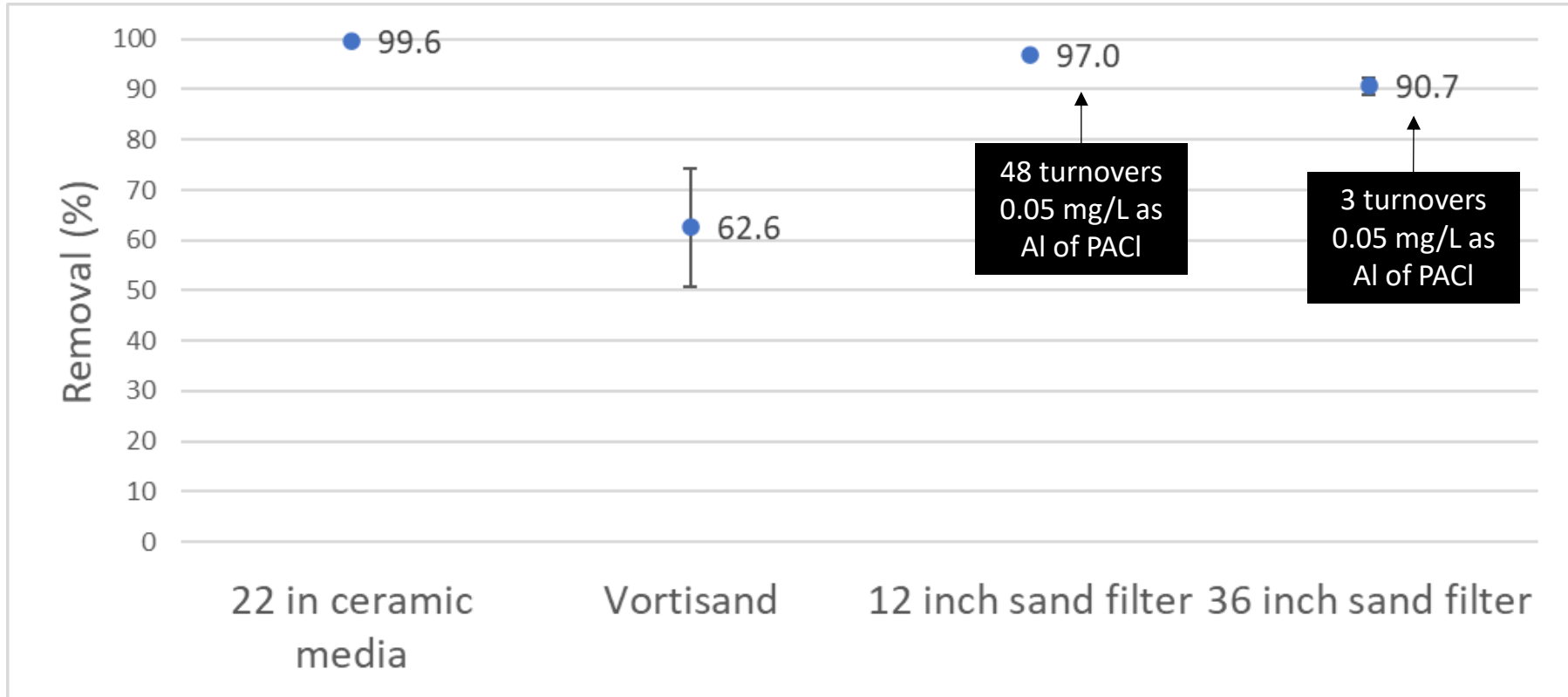


* Lab scale

No-coagulation Summary (+ TOC)



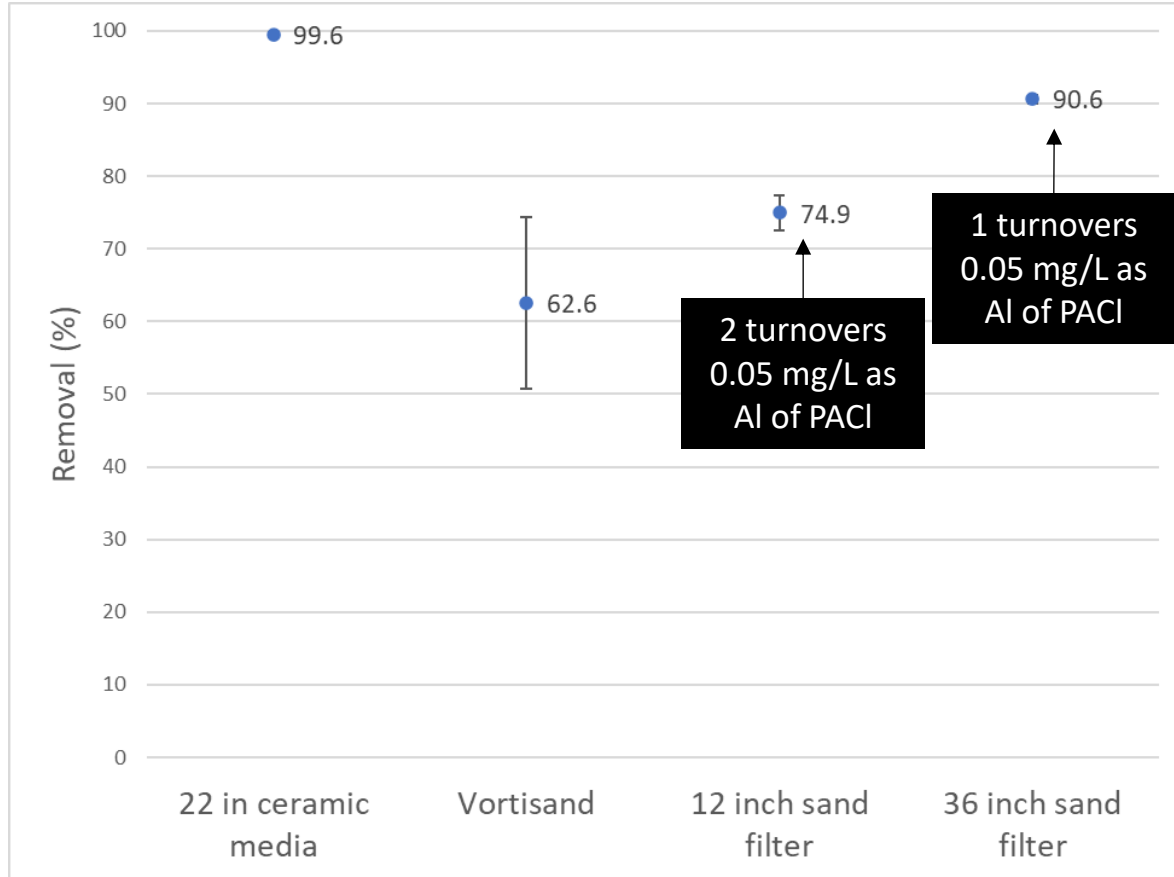
Overall Summary



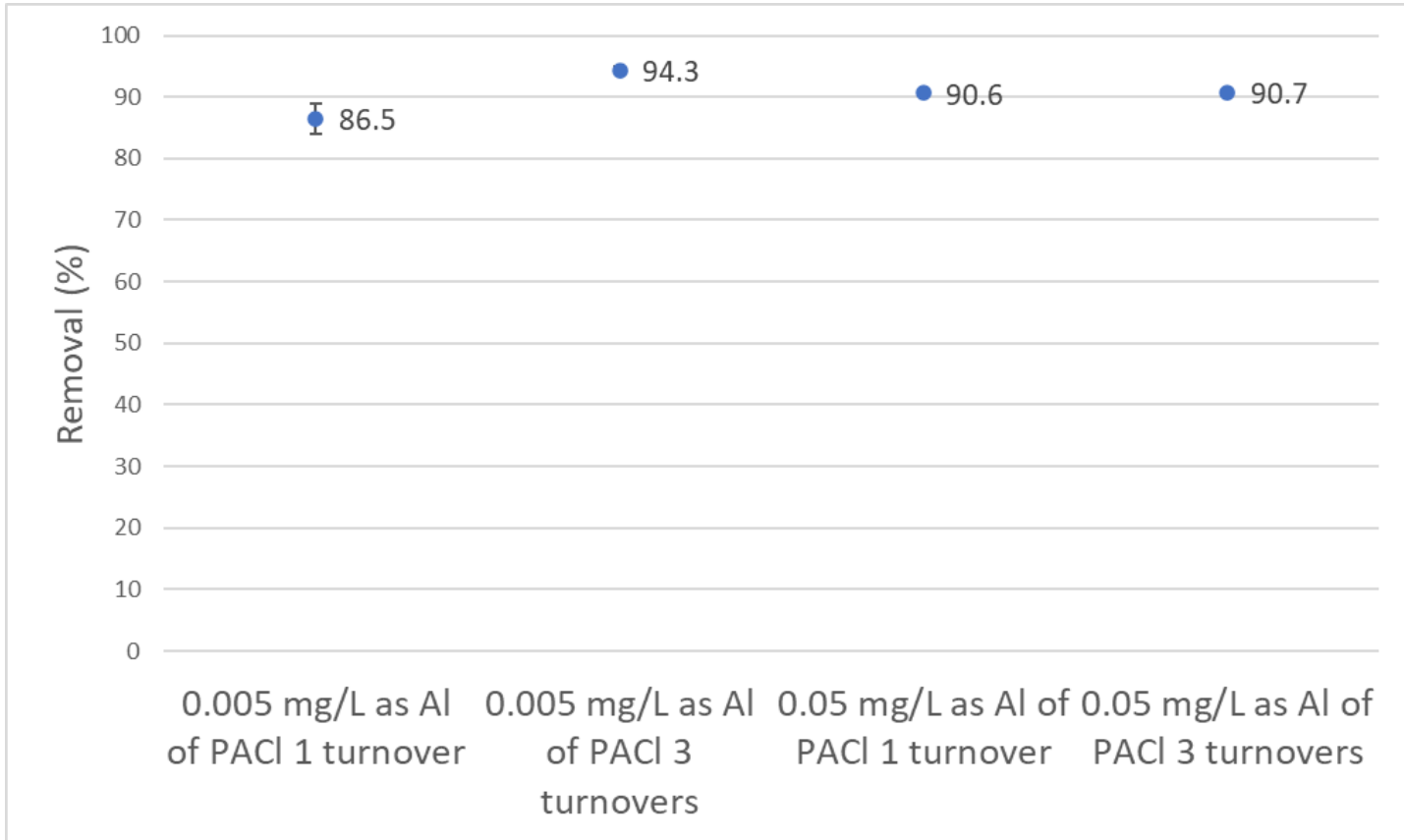
Statistical Analyses

- Ceramic media filter performed better than both of the highest removals of the sand filters with coagulation experiments:
 - Ceramic vs. 12-inch @ 48 turnovers w/ 0.05 mg/L as Al
 - P-value 6.99×10^{-7}
 - Ceramic vs. 36-inch @ 3 turnovers w/ 0.05 mg/L as Al
 - P-value 1.01×10^{-5}

Early-bird Summary



36-inch Sand Coagulation Experiments (+ TOC)



Conclusions (1 of 2)

1. With **no** bather load (**TOC**), the **12-inch sand** filter had a removal of 99.8% at 2 turnovers and 99.9% at 48 turnovers with 0.05 mg/L as Al of coagulant.
2. With bather load addition (**+ TOC**), the **12-inch sand** filter removals dropped to 74.9% at 2 turnovers and 97.0% at 48 turnovers.
3. **To simulate realistic recreational water treatment in laboratory experiments, TOC should be added to simulate bathers.**
4. The **36-inch sand** filter removals drop by 1-2 orders of magnitude (1-2 log) with bather load addition (**+ TOC**). Yet, with 0.005 mg/L as Al of PACl or more, removals remained at or above 86.5% at ~1 and ~3 hours after backwashing.

Conclusions (2 of 2)

5. 22-inches of **Ceramic media** (Cerafow-70) initially had a microsphere removal of 99.6%, but after 8 weeks of a constant **+TOC** loading of **+2 ppm**, the microsphere removal dropped to only 49.8%.
6. **Ceramic media** regeneration experiments were not successful in completely recovering the initial performance of the media.
7. The **Vortisand filter** had an initial microsphere removal of 62.6% and was not recommended for use with coagulants by the manufacturer. So, it does not appear to be well-suited to swimming pool water treatment applications.
8. While sand filtration with coagulation might not be as good as we once thought (**86.5% vs. >99%**), the alternatives tested still have short-comings that must be addressed.

$$FT_{99.9\%} = 6.91 * \frac{6 \text{ hrs.}}{0.865} = 47.9 \text{ hrs.} = 2.0 \text{ days}$$

$$FT_{99.9\%} = 6.91 * \frac{6 \text{ hrs.}}{0.999} = 41.5 \text{ hrs.} = 1.7 \text{ days}$$

Acknowledgements

- **Xylem** for Funding this important new Research
- My Research Team (especially Wesley & Graham)...
- Amir Alansari and amiralansari.com
- Scott, Aneta, Amanda, Michele, Michael, Doug, Sean, Mike, Jim, Tom, Derek, Ben, Jake, Steve, Sevang, Jon, Herve, Will, Neal, Brian, Todd, Ann, and so many others...
- You for joining me today!



Questions?

A yellow starburst graphic with a black outline, containing the email address James.Amburgey@charlotte.edu.

James.Amburgey@charlotte.edu

How long does it take to remove 99.9% of the *Crypto* in a pool?

Treatment Ratio (TR)= 24 hrs.


$$FT_{99.9\%} = 6.91 * \frac{6 \text{ hrs.}}{0.25} = 6.91 * 24 \text{ hrs.} = 166 \text{ hrs.} = 6.91 \text{ days}$$

where:

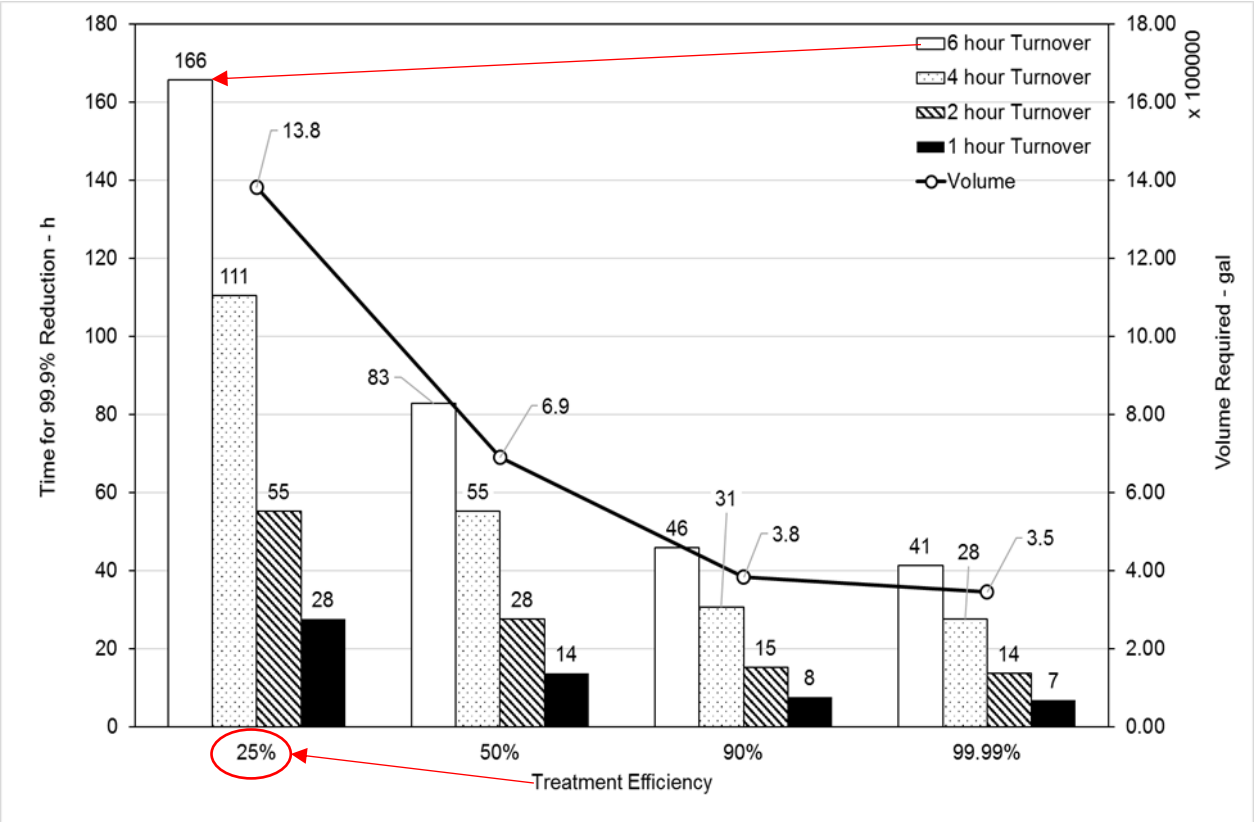
$FT_{99.9\%}$ = Filtration Time required for (n=99.9%) overall removal

turnover time = pool turnover time (= pool volume/filter flow rate) 6 hrs.

filter efficiency = filter removal per pass (in decimal form) 25% = 0.25

3-log Treatment time depends on the Turnover & Filter Efficiency

(Filtration Time = 6.91 x Turnover/Filter Efficiency = 6.91 x TR)



Alansari, Amburgey, and Madding (2018) *Journal Water & Health* 16(3):449-459.

“The Law of Dilution” = % Water Filtered

Turnovers (t)	1	2	3	4	5	6	10
Gage - Bidwell	63	86	95	98	99.3	99.7	99.99
Exponential Decay Model	63.2	86.4	95.0	98.2	99.3	99.7	99.995

$$Removal = 1 - e^{-t}$$

*where “e” is a constant (~2.718)

- Download your free copy of this software here:

<https://www.amiralansari.com/recreational-water>

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Spray Pad Simulator 1.0

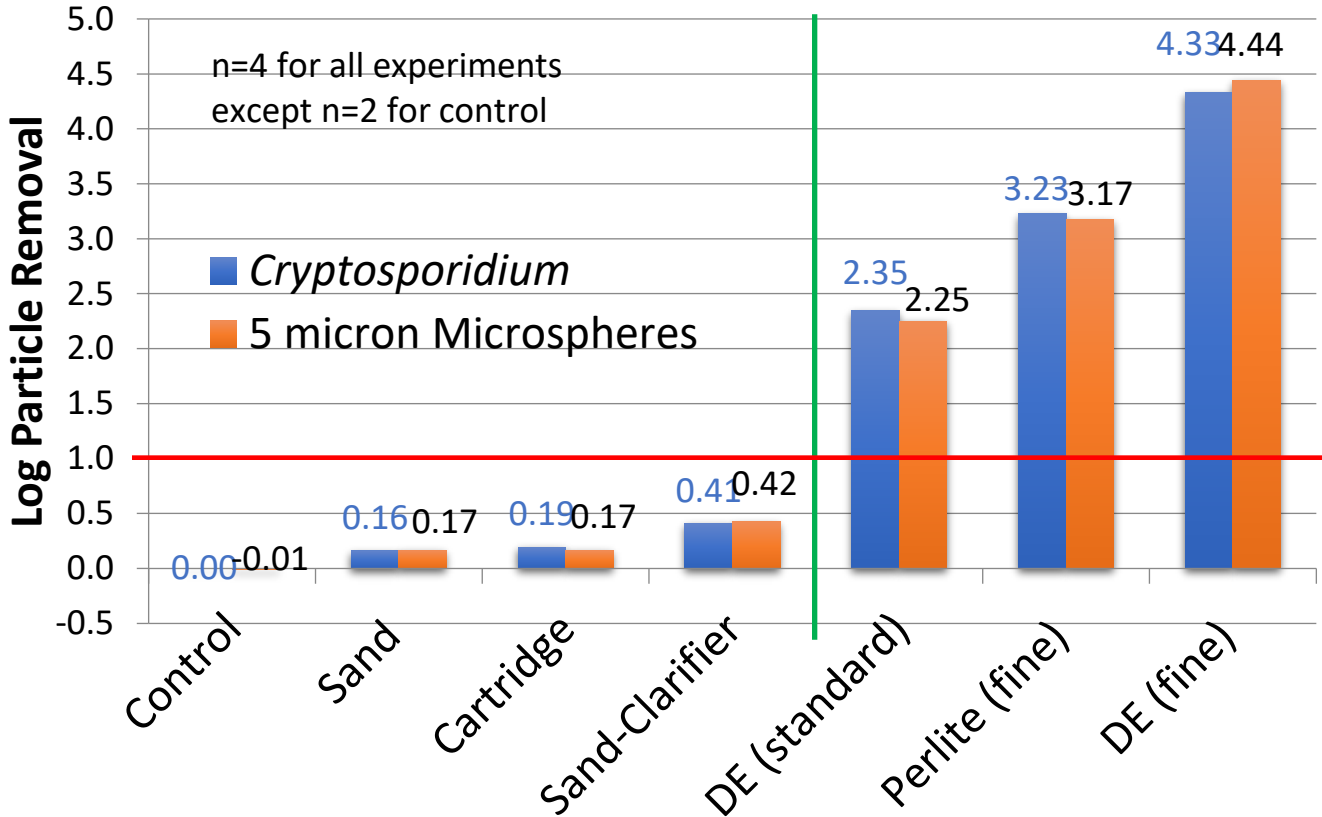


Suppose there was a fecal contamination incident at the spray pad shown in the picture above. How long would it take until the water is *safe* again? would it be minutes? hours? or days? Should you drain some of the water? increase the turnover rate? or both? What is the best strategy to clean the water as quickly and efficiently as possible?

Let's Chat!

Summary: **Crypto** & **Microspheres**

Source: Amburgey et al., 2012. *Journal of Water & Health*



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Removals of cryptosporidium parvum oocysts and cryptosporidium-sized polystyrene microspheres from swimming pool water by diatomaceous earth filtration and perlite-sand filtration

Ping Lu, James E. Amburgey, Vincent R. Hill, Jennifer L. Murphy, Chandra L. Schneberger...

J Water Health (2017) 15 (3): 374-384.

DOI: <https://doi.org/10.2166/wh.2017.221>

Date Online: 24 February 2017

...Ping Lu, James E. Amburgey, Vincent R. Hill, Jennifer L. Murphy, Chandra L. Schneberger, Michael J. Arrowood, Tao Yuan Removal of Cryptosporidium-sized microspheres and Cryptosporidium parvum oocysts from swimming pools was investigated using diatomaceous earth (DE) precoat filtration and perlite...

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Amir Alansari, James Amburgey, Nathan Madding

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DOI: <https://doi.org/10.2166/wh.2018.223>

Date Online: 04 April 2018

...Amir Alansari, James Amburgey, Nathan Madding Abstract: The primary objective of this study was to conduct a quantitative analysis of the hydraulic efficiency of a 1:25 bench-scale swimming pool and to determine whether the recirculation efficiency could be increased by modifying parameters such as...

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Removal of Cryptosporidium and polystyrene microspheres from swimming pool water with sand, cartridge, and precoat filters

James E. Amburgey, Kimberley J. Walsh, Roy R. Fielding, Michael J. Arrowood

J Water Health (2012) 10 (1): 31-42.

DOI: <https://doi.org/10.2166/wh.2011.062>

Date Online: 14 October 2011

...James E. Amburgey, Kimberley J. Walsh, Roy R. Fielding, Michael J. Arrowood Cryptosporidium has caused the majority of waterborne disease outbreaks in treated recreational water venues in the USA for many years running. This research project evaluated some common US swimming pool filters for...

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A pilot-scale study of Cryptosporidium-sized microsphere removals from swimming pools via sand filtration

Ping Lu, James E. Amburgey

J Water Health (2016) 14 (1): 109-120.

DOI: <https://doi.org/10.2166/wh.2015.047>

Date Online: 14 September 2015

...Ping Lu, James E. Amburgey Cryptosporidium species are the most common cause of gastrointestinal illness in treated recreational water venues. In order to protect public health during swimming, Cryptosporidium-sized microsphere removals by high-rate sand filtration with six coagulants were...

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James E. Amburgey, J. Brian Anderson

J Water Health (2011) 9 (4): 653-658.

DOI: <https://doi.org/10.2166/wh.2011.063>

Date Online: 14 September 2011

...James E. Amburgey, J. Brian Anderson Cryptosporidium is a chlorine-resistant protozoan parasite responsible for the majority of waterborne disease outbreaks in recreational water venues in the USA. Swim diapers are commonly used by diaper-aged children participating in aquatic activities. This...

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JOURNAL ARTICLES

Turbidity reduction in drinking water by coagulation-flocculation with chitosan polymers

Ampai Soros, James E. Amburgey, Christine E. Stauber, Mark D. Sobsey, Lisa M. Casanova

J Water Health (2019) 17 (2): 204-218.

DOI: <https://doi.org/10.2166/wh.2019.114>

Date Online: 14 February 2019

...Ampai Soros, James E. Amburgey, Christine E. Stauber, Mark D. Sobsey, Lisa M. Casanova Abstract Turbidity reduction by coagulation-flocculation in drinking water reduces microbes and organic matter, increasing effectiveness of downstream treatment. Chitosan is a promising household water coagulant...

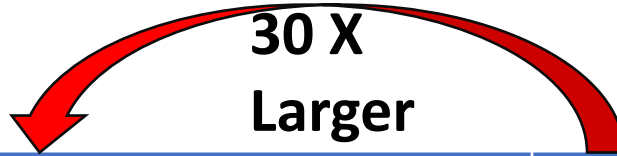
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JOURNAL ARTICLES

Role of filtration in managing the risk from Cryptosporidium in commercial

Sand vs. Perlite (grain size)

**30 X
Larger**



Filter media materials	Sand	Perlite
Effective Size (d_{10} , μm)	485	16.9
d_{60} (μm)	726	50.37
d_{90} (μm)	993	92.3

Expected Pore Size: 10% of 485 = **48.5 μm**

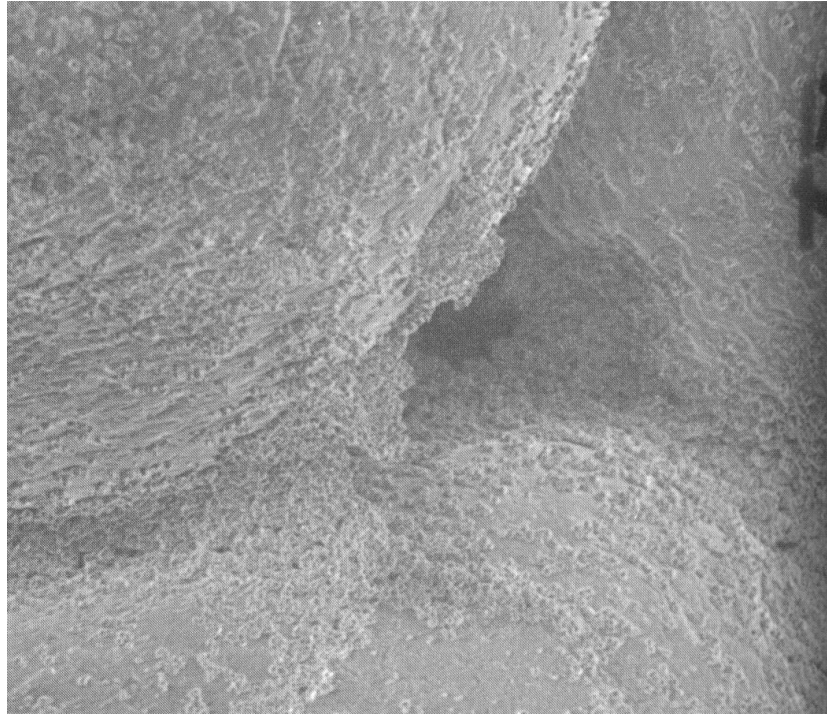
Cryptosporidium Size: **(10 X smaller) 4.5 μm**

10% of 16.9 = **1.69 μm**

(3 X larger) 4.5 μm

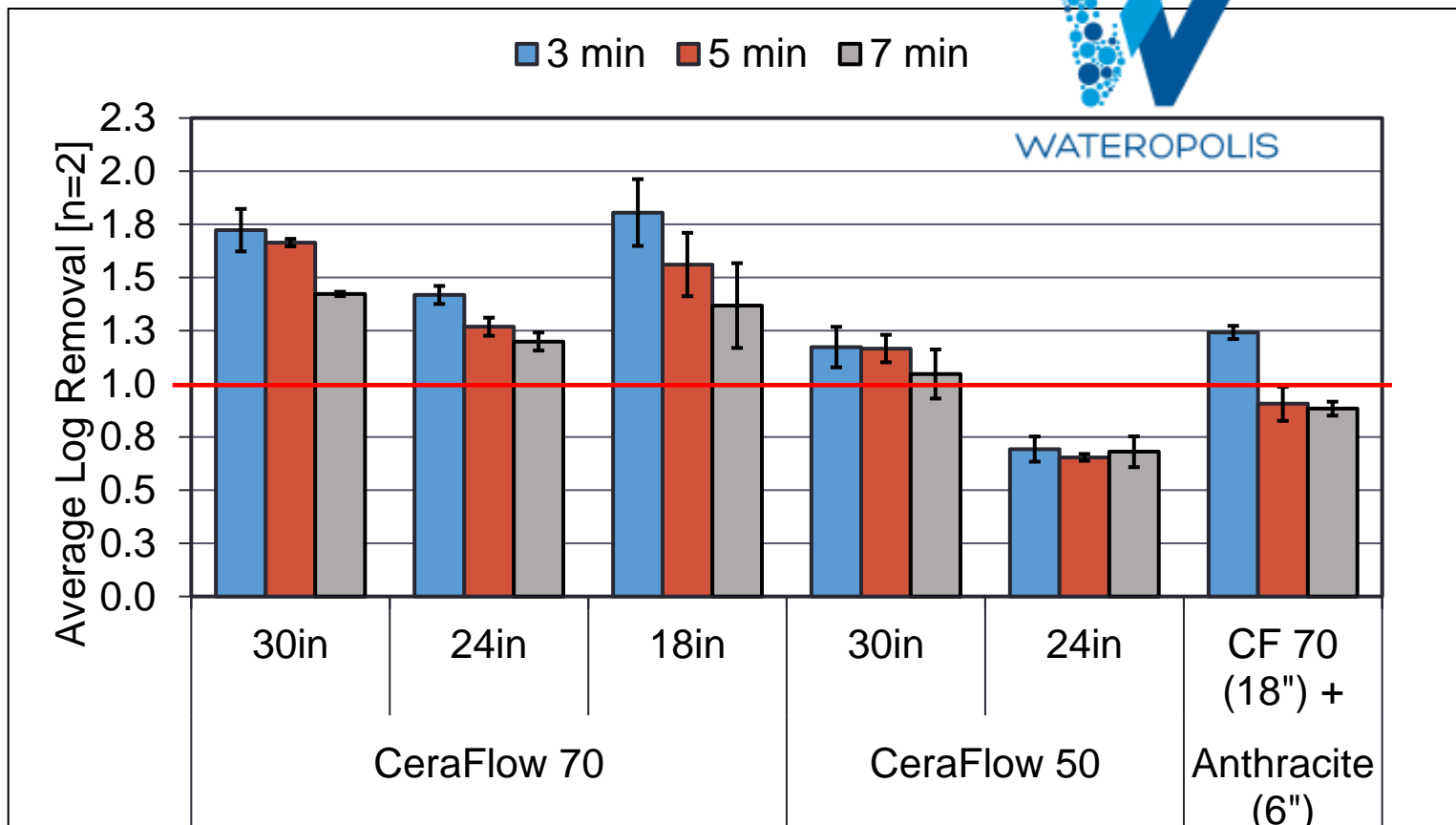
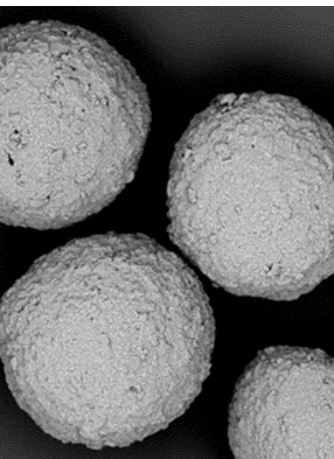
Image from Inside of a Sand Filter

- SEM of 1 mm sand grains
- Filtering 5-10 micron silicate particles
- At 46 cm into bed after 3 hrs



Graphic: Courtesy of Water Quality & Treatment 4th ed.

Ultrafine Ceramic Sand (CeraFlow)



Crypto-sized Microsphere Removals

Average Removals (n=2)							
Time [min]	CeraFlow70			CeraFlow50		Anthracite	CF50
	30in	24in	18in	30in	24in	18in CF70 + 6in Anthracite	24in -10um
3	98.1	96.2	98.4	93.3	79.7	94.3	> 99.987
5	97.8	94.6	97.3	93.2	77.8	87.6	> 99.987
7	96.2	93.7	95.7	91.0	79.1	86.9	> 99.987

Media Source: Wateropolis (<http://www.wateropolis.com/>)



2020-2021 Filter Test Results

- Regenerative Media Filters (RMF's)

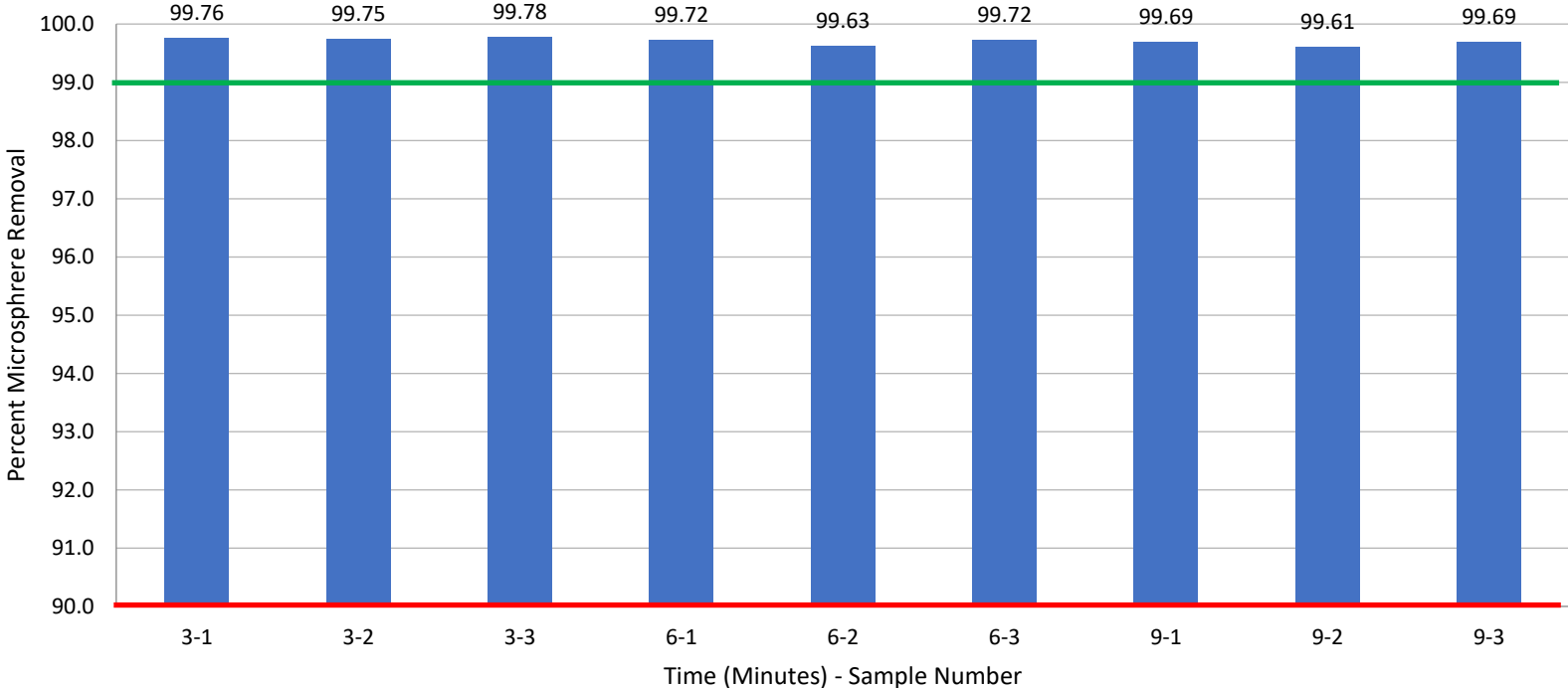


Neptune Benson
an EVOQUA brand

Defender Filter

Baseline Defender RMF Conditions

Percent Removals



Crypto Outbreaks Are Multi-level Failures:

- 1. Chlorination (too little, CYA, chloramines, pH high)
- 2. Filtration (too fast, too little coagulant, not enough media)
- 3. Dilution (insufficient volume)
- 4. Occupancy limits (none, too high, not enforced)
- 5. Operation (no backwashing, no water replacement, inconsistency)
- 6. Design (long turnover time, no ozone, sidestream UV)
- **7. Regulatory (pools all differ, regulations all the same) (no unified goal or governing equations) (total reliance on chlorine)**
- 8. Educational (swimming while ill, or within 2 weeks of illness)
- 9. Epidemiological (community-wide spread, poor hygiene)
- 10. Diagnostic (90% of *Crypto* outbreaks/cases go undetected)