How to **Filter** your aquatic venue **Smarter Now**... for safer and cleaner water

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*The WILLIAM STATES LEE COLLEGE of ENGINEERING*
How to know if your current filter is TERRIBLE at Removing Crypto…

• Hands up!
• You do not follow MAHC guidelines
• You do not rely on CDC guidance for AFR’s
• Your CPO’s do not follow NSPF and State guidelines
• Your pool designer didn’t follow State requirements
• You disregard your filter manufacturer’s written guidelines.
• Your filter or media is not NSF certified
Here’s the Bottom line…

• From operation & maintenance issues to poor design, your filters problems are just a matter of time.
• Even filters meeting all current industry standards are likely to have serious problems and perform very poorly.
• Understanding pool filters will help you to recognize and solve some of those problems… or maybe even prevent them!
• Water quality (and public health) depend on filter performance in conjunction with the recirculation system. Chlorine is just not enough!
The MAHC

• The filtration & recirculation sections of the MAHC are among the very best I’ve seen.
• I chaired the technical committee that wrote them, so I might be biased.
• Let’s take a closer look… at the 3 major filter types
The MAHC says…
Sand (Granular Media) Filters

• Capability to remove and replace media
• 15 gpm/sq. ft. (with at least 15” of media depth); otherwise 12 gpm/sq. ft.
• Backwash rate: at least 15 gpm/sq. ft.
• Coagulant injection systems (optional) and upstream of filters
• Backwashing while pool is closed to bathers
• Annual filter media inspections
These requirements are probably…

• Better than whatever your state or local jurisdiction requires
• Are a good first step in the right direction
• Are NOT going to reliably and efficiently remove Crypto!
Want to **Filter Smarter Now?**
Here is how with Sand (Granular Media) Filters…

- Capability to remove and replace media
- 10 gpm/sq. ft. (with at least 24” of media depth)
- Backwash rate: at least 20 gpm/sq. ft.
- Coagulant injection systems (**REQUIRED**) upstream of filters (at least 0.1 mg/L as Al; polyaluminum chloride preferred)
- Backwashing while pool is closed to bathers
- Annual media inspections
The MAHC says…
DE (Precoat) Filters

- Filtration rate: up to 2 gpm/ft$^2$ (or 2.5 gpm/ft$^2$ with body feed)
- Precoat method: up to manufacturer
- Media discharge: in accordance with local regulations
- Type and quantity of media: per manufacturer
- Bumping filters: per manufacturer
Want to Filter Smarter Now? Here is how with DE (Precoat) Filters…

- Filtration rate: up to 2 gpm/ft² (or 2.5 gpm/ft² with body feed)
- Precoat method: closed loop, no flow interruption to go online
- Media discharge: in accordance with local regulations
  - Don’t allow anyone to Inhale Precoat Filter Media Dust
  - Don’t Discharge DE into any sewer pipes
  - Perlite is preferred (and performance is brand and grade dependent)
- Type and quantity of media: At least 0.73 kg/m² (1.5 lbs/10 sf) DE = 0.37 kg/m² (.75 lbs/10 sf) Perlite. Dose is based on volume (not weight)
- Bumping filters: Don’t do this unless your filter was designed and tested for doing this.
Cartridge Filters

- Filtration rate: up to 0.375 gpm/sq. ft.
- Spare cartridges: 2\textsuperscript{nd} set required onsite and ready for use.
Want to **Filter Smarter Now?**
Here is how with Cartridge Filters

- Don’t use them…
- Good cartridge filter technology already exists (for filtering 1 or 5 micron particles), but it is not being used in pools or spas because it would clog too rapidly.
- 30 micron rated cartridges do not clog as fast, but they do not remove *Crypto* efficiently or reliably either.
- Two cartridge filters in series (30 micron first; 5 micron second) could work for pools, but it would double the number of required filters and cartridges, which would undoubtedly cost hundreds of dollars for some venues.
- Add perlite to a cartridge filter?
Quick Recap

• You do everything you’ve been taught
• You listened to the experts (designers, builders, operators, regulators, manufacturers, and NSF)
• Your filters are terrible at removing *Crypto*!
• Filter problems are just a question of when.

• You really need to **Filter Smarter Now!**
NSF 50 Filter Performance Testing

“70% turbidity reduction …using Sil-co-sil 106 (#140 silica), after 5 volumetric turnovers in accordance with section 5 and annex B.”

<table>
<thead>
<tr>
<th>B.5.3 Challenge water</th>
<th>swimming pool/spa/hot tub filters</th>
</tr>
</thead>
<tbody>
<tr>
<td>water temperature</td>
<td>75 ± 10 °F (24 ± 6 °C)</td>
</tr>
<tr>
<td>turbidity prior to adding silica</td>
<td>≤ 2 NTU</td>
</tr>
<tr>
<td>turbidity after adding silica #140</td>
<td>45 ± 10 NTU</td>
</tr>
</tbody>
</table>
NSF 50 Filter Performance Testing

• **Goal:** 70% reduction in 5 turnovers (that is 21.4%, 5 times)
• If the filter passes, the water is still really cloudy (~10-17 NTU)
• **Particles:** yes, let’s use **really large, high-density particles** (much larger than *Crypto*) so a crappy filter can actually remove them.
• When you were in school and scored 21.4% on an exam, did you get a gold star?
• NSF could stand for **Nope, Sorry, Failed!**
Figure 1. Particle size distribution for SCS 106. Sand/silt/clay fractions according to USDA definitions are approximately 20%, 80%, and 0% for SCS 106, indicating that the texture corresponds to a silt material.
NSF 50 Recap

- Certification has nothing to do with how well they move Crypto, or any bacteria, virus, or microorganism.
- If a filter was really, really good and removed everything down to 1 micron, then it would probably clog quickly and fail this test... where the water is about the color of milk.
- The best filters I’ve ever seen would fail NSF 50.
- The filters that pass NSF are some of the worst I’ve ever seen.
Next step…

• Now that we know how to make filters work…
• And how NOT to test them…
• Let’s take a look at how we have to get the water to the filter to be filtered (either well or poorly).
166 hours = 6.92 days
166 hours = 6.92 days

3 Log Reduction (10 million to 10 thousand)

28 turnovers
166 hours = 6.92 days

3 Log Reduction (10 million to 10 thousand)

31 hours = 1.29 days

28 turnovers

25%
166 hours = 6.92 days

3 Log Reduction (10 million to 10 thousand)

28 turnovers

31 hours = 1.29 days

28 hours = 1.17 days

UV, Ozone, Membranes, ($$$$

25%  50%  90%  99.99%

31
Setting the Bar

• How good is a good pool filter at removing *Crypto*?
  • 90%, maybe even 99%, but not 99.9% or 99.99%.
• How good is a pool at getting water to a filter?
  • 63% is as good as it gets
• How about a spray pad?
  • Sidestream (63%)
  • Fullstream (100%)... changes the game entirely!
Pop Quiz

• 1. Is NSF 50 certification proof that a filter is good at removing Crypto?
• 2. How efficient do we really need a pool filter to be?
• 3. How can you tell if your swimming pool filter is bad at Crypto reduction?
How do we make pool filters efficient at removing chlorine-resistant human pathogens like *Crypto*?
Sand Filters

They are great as is, unless you are trying to remove *Crypto*, *Giardia*, bacteria, or viruses.

- 1. The holes in the sand are too big
- 2. The particles and sand are negatively charged.

  - **Option #1:** Use ultrafine ceramic media
  - **Limitations:** need ~24” of sand, filter at < 10 gpm/ft²

  - OR

  - **Option #2:** Add alum or Polyaluminum Chloride (PACl) to reduce negative charge on particles
  - **Limitations:** need 24” of sand, filter at < 10 gpm/ft², and dose at a minimum of 0.1 mg Al/L
# Ultrafine Ceramic Sand (Ceraflow)

## Average Log Removal [n=2]

<table>
<thead>
<tr>
<th>Layer</th>
<th>3 min</th>
<th>5 min</th>
<th>7 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>30in</td>
<td>1.8</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>24in</td>
<td>1.8</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>18in</td>
<td>1.8</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>30in</td>
<td>1.5</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>24in</td>
<td>1.5</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>CF 70 (18&quot;) + Anthracite</td>
<td>1.5</td>
<td>1.3</td>
<td>1.1</td>
</tr>
</tbody>
</table>

- CeraFlow 70
- CeraFlow 50
- Anthracite
Percent removals of 4.5μm microspheres by loading rate and sand depth

Standard European practice
Canada approved
Amburkey recommended!
Not Required = T-Rex?

Standard US practice
NSF Approved
MAHC approved
State approved

Loading Rate (m/h):
- 25
- 37
- 10 gpm/sf
- 15
- 25
- 30
- 37
- 15

Sand Depth (cm):
- 60
- 60
- 30
- 30
- 24”
- 24”
- 12”
- 12”

Condition Label:
- A
- B
- C
- D
Vertical vs. Horizontal Filters

More than one way to do it wrong!


https://www.hayward-pool.com/shop/ProductDisplay?urlRequestType=Base&catalogId=10057&categoryId=581&productId=4229623&urlLangId=-1&langId=-1&parent_category_rn=&storeId=10201
Want to **Filter Smarter Now?**
Here is how with Sand (Granular Media) Filters…

- Capability to remove and replace media
- **10 gpm/sq. ft.** (with at least 24” of media depth)
- Backwash rate: at least **20 gpm/sq. ft.**
- Coagulant injection systems (**REQUIRED**) upstream of filters (at least 0.1 mg/L as Al; polyaluminum chloride preferred)
- Backwashing while pool is closed to bathers
- Annual media inspections
Can’t put 24” of sand in a 12” filter!

## Sand vs. Perlite (grain size)

<table>
<thead>
<tr>
<th>Filter media materials</th>
<th>Sand</th>
<th>Perlite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Size ($d_{10}$, µm)</td>
<td>485</td>
<td>16.9</td>
</tr>
<tr>
<td>$d_{60}$ (µm)</td>
<td>726</td>
<td>50.37</td>
</tr>
<tr>
<td>$d_{90}$ (µm)</td>
<td>993</td>
<td>92.3</td>
</tr>
</tbody>
</table>
DE in a Sand Filter

Amount: 0.5 lbs/ft²
Depth: 6-8 mm (1/4” +)
Hard to remove via backwashing
Perlite is much less dense!
Precoat Media & Surface Filtration
DE & Perlite work great (in DE Filters)… except for 1-micron Particle Removal

Source: Amburgey et al., 2012. *Journal of Water & Health*
Flow Interruption / “Bumping”

Microsphere Removals by DE Filtration Before and After Filter Bumping under Different Amounts of Precoat and Different Filtration Rate of 6 m/h, 5 m/h, and 3.6 m/h, with a 15-minute Filter Stop

Performance depends on the Amount of Precoat Media Used

At least 0.73 kg/m$^2$ (1.5 lbs/10 sf) DE = 0.37 kg/m$^2$ (.75 lbs/10 sf) Perlite. Dose is based on volume (not weight), Yes, 50% more than current standard!

Ceramic Membranes (SiC) .25 & 4 micron pore size & chemically inert.

• This Silicon-Carbide Membrane was able to achieve an average of 4.4 Log (99.996%) Removal of Cryptosporidium-Sized Microspheres under simulated swimming pool conditions.

Source: SAINT-GOBAIN
How do we make pool filters efficient at removing chlorine-resistant human pathogens like *Crypto*?

Sand
Precoat
Cartridge
Membranes
Effective Ways to Filter Pools

• 1. Sand Filters should have 24” of sand, filter at < 10 gpm/ft^2, and dose a minimum of 0.1 mg Al/L as PolyAluminum chloride
• 2. Sand filters with Ultrafine Ceramic Media
• 3. Sand filters with 2.5 lbs. Perlite/10 ft^2 of sand surface area
• 4. Precoat Filters should dose at least 0.73 kg/m^2 (1.5 lbs/10 ft^2) DE = 0.37 kg/m^2 (.75 lbs./10 ft^2) Perlite. Yes, **50% more** than current standard! **Flow interruptions** should be avoided without replacing the media (and precoating offline)
• 5. Cartridge filters should add a second stage of smaller pore-size rated cartridges.
• 6. Ceramic membranes are the cat’s pajamas! Just not in the MAHC or allowed by State Regulators and couldn’t pass NSF 50.
Got a high-risk venue like a spray pad?

- The MAHC recommends a UV system validated for 3 Log (99.9%) Crypto Inactivation by US Drinking Water Standards.
- This option is a little expensive, but it should work fine on most pools.
- **How do you make it FAIL?**
  - Reduce the volume of water, add more people, and spray UV blocking Sunscreen on them… let’s call it a spray pad!
  - The UV gets blocked by the sunscreen in the water just like the sunscreen blocks the UV from the sun to prevent sunburns.
  - Don’t worry, we can simply filter out the Crypto!
  - Nevermind, we designed and use sand filters that meet all State, NSF, CDC, Pool Designer, and Manufacturer’s Guidelines. So, they might only average 25% Crypto Removal.
Want to Solve the *Crypto* Outbreak Problem?

You can’t be afraid to pull out your wallet and exceed the minimum standards set by the MAHC, States, NSF, Pool Designers, and Manufacturers.

- At least 24” of sand
- Filter at < 10 gpm/ft²

- 1.5 lbs/10 ft² DE = .75 lbs/10 ft² Perlite
  - Yes, 50% more!

- 5 lbs/10 ft² DE on Sand = 2.5 lbs/10 ft² Perlite

- Dose 0.1 mg Al/L of PACl
  - PolyAluminum chloride

- Ceramic Membranes

- Ultrafine Ceramic Sand (Ceraflow)

At least 24” of sand, filter at < 10 gpm/ft²
You might have to fight through many obstacles to get filters that work...
What have we learned so far?

• We can simply meet every minimum standard, or we can **Filter Smarter Now!**

• The filtration and recirculation section of the MAHC is great... **But it is only a common starting point (not the ultimate goal).**

• We’ve made filters so cheap that they no longer work for anything but appearances!
Would you like to have a pool design guide on how to **Filter Smarter Now!**

- Would you like it for free?
- Do you want it right now?
Free Aquatics Design Examples...


- http://www.wateropolis.com/resources/
We know how to filter pools much more efficiently than current practice, but…

- **Designers** are shooting for the minimum standard and poor specs most of the time.
- **CDC folks** are all into chlorine and UV, which both have their share of issues. What about giving filters some credit?
- **Aquatics managers** have the authority to change filtration practices. What should they change?
- **CPO’s** need to inspect and verify filters are working, but they can also suggest changes to managers.
- **Presenters at conferences** NEED to tell folks exactly what they can do to **Filter Smarter Now!**
Common Filter Maintenance Problems

Leaks (multiports, air bleed valves, flanges, o-rings connections, ect.)

Broken handles on valves

Cracks in pipe, tanks, and fittings

Broken pressure gauges (not following logic…)

Acrylic flowmeters (dirty and/or stuck)
Common Filter Operating Problems

Poor water quality
- Dirty Filter Media, clean it. Could be caused by infrequent, short backwashing procedures.
- No Filter media, replace it. *Use correct sand size, cover laterals with water before adding media
- Use correct amount of DE
- Heavy bather load. Wait a while.

Filter media in pool
- Broken Lateral (sand filter)
- Torn support layer (precoat filter)

Cleaning filter required too frequently
- Poor cleaning procedure.
- Might only be a perceived problem...
- Filters that work are supposed to clog!

Common Filter Design Problems

Cartridge filter.

**Sand filter:** (<24” of media, filter >10 gpm/ft², backwash <20 gpm/ft², or <0.1 mg Al/L coagulant)

**Precoat filter:** (flow interruption between coating and filtering modes)

**Pool turnover time.** Inappropriate for bather load (e.g., a 6 hr. turn & heavy bather load)

Basing flow rates on **inaccurate flow meters** (e.g., Acrylic or paddle wheel).
Great, I’m not a Pool Designer, what can I do?

You should understand the basic design principles just in case the designer doesn’t.

You should require a qualified engineer that understands these design principles to review your designer’s proposed design.
Long list of excellent engineers I would highly recommend for pool filter design reviews:

Dave Schwartz, PE
Waters Edge Aquatic Design
dschwartz@wedesignpools.com
Big Picture Design Objectives

• How many pumps?
• How many filters?
• How to decide?
Bad / Typical Design
(filtration rate = backwash rate ~ 15 gpm/ft²)
Improved Design (backwash flow ~ 20 gpm/ft\(^2\) can be double the filtration ~ 10 gpm/ft\(^2\))
Better Design (Variable drives control flows without wasting energy)
Design Calculations & Applications

• What makes a good filter design?
• A. Calculating and using filtration rates and backwashing rates
• B. Chemical & media dosing calculations
• C. Calculating pool turnover time and its relationship to filter performance

• Bring it all together: Combining the filter efficiency & recirculation efficiency
1. Filtration rates & Backwashing rates

- **Calculate design parameter:** Flow/Filter Surface Area = 10 gpm/ft$^2$
- For example, a 36” diameter filter has a diameter of 3 ft. (radius = 1.5 ft)
- Area of a circle = $\pi \times \text{radius}^2 = 3.14 \times \text{radius} \times \text{radius}$
- Area = $3.14 \times (1.5 \text{ ft}) \times (1.5 \text{ ft}) = 7.07 \text{ ft}^2$ (Surface area of filter)
- Now: $\text{Flow}/(7.07 \text{ ft}^2) = 10 \text{ gpm/ft}^2$
- What is the maximum flow rate to achieve a loading rate of 10 gpm/ft$^2$?
- Max flow = $10 \text{ gpm/ft}^2 \times 7.07 \text{ ft}^2 = 70.7 \text{ gpm}$ (or 70 gallons per min.)
- Filter at 70 gpm (or 10 gpm/ft$^2$), and backwash at 140 gpm (or 20 gpm/ft$^2$).
- Of course, NSF and the design engineer will tell you the filter is certified to filter at 20 gpm/ft$^2$ and they want to design it (wrong) to both filter and backwash at 15 gpm/ft$^2$, which will meet all of the required State/MAHC minimum standards.
2. Filter Media Specs

- Effective Size (ES) = $d_{10}$
- Uniformity Coefficient (UC) = $d_{60} / d_{10}$
- $d_{10}$, $d_{60}$, and $d_{90}$ (% weight smaller than size)

- The specified filter sand will cost more than the local “pool filter sand” from the pool store… because it is worth it!
Grainsize distribution of sand
3. What is Fluidized Backwash?

• Failure to backwash properly leads to…
• Your filter sand continually gets dirtier (due to poor cleaning) until you must replace it.
Backwash Rates also Vary with Temperature

- 0.55 mm E.S. sand with U.C. of 1.5 & density of 2.65 g/cm³

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>Recommended Wash Rates (1.3*Vmf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11.7 gpm/sq. ft.</td>
</tr>
<tr>
<td>5</td>
<td>13.5 gpm/sq. ft.</td>
</tr>
<tr>
<td>10</td>
<td>15.3 gpm/sq. ft.</td>
</tr>
<tr>
<td>15</td>
<td>17.1 gpm/sq. ft.</td>
</tr>
<tr>
<td>20</td>
<td>19.0 gpm/sq. ft.</td>
</tr>
<tr>
<td>25</td>
<td>20.7 gpm/sq. ft.</td>
</tr>
<tr>
<td>30</td>
<td>22.4 gpm/sq. ft.</td>
</tr>
</tbody>
</table>

- **Recommendation**: Use 0.5 mm E.S. sand with U.C.<1.5 to backwash at 20 gpm/ft² with water temperature up to 30° C (86° F).
## What happens at less than 20% Bed Expansion?

<table>
<thead>
<tr>
<th>Backwash Flow (gpm/ft²)</th>
<th>Bed Expansion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.4</td>
<td>3.6</td>
</tr>
<tr>
<td>16.3</td>
<td>11.4</td>
</tr>
<tr>
<td>18.5</td>
<td>16.3</td>
</tr>
<tr>
<td><strong>20.3</strong></td>
<td><strong>19.3</strong></td>
</tr>
<tr>
<td>22.1</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Dirty media due to Ineffective Backwashing can cause pressure to build up fast and cloudy water in the pool.
Cloudy water in a shallow pool with undersized horizontal sand filter… Dirty sand after inadequate backwash (<15 gpm/ft²)
4. Other Common Filter Problems

• Broken laterals (sand in pool)
• Stagnant area beneath laterals (becoming a bioreactor)
5. Dosing coagulant (PACl or PAX)

- 9% aluminum
- Only 9% of solution is aluminum, 100 mg contains 9 mg Al.
- Specific Gravity is 1.37
- S.G. of 1.37, means 100 mL of liquid weighs 137 grams, which is heavier than water with a S.G. of 1.00

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**PAX-18**

Polyaluminum Chloride

Kemira’s PAX-18 is a high performance liquid polyaluminum chloride coagulant that generally offers superior clarification in either potable or wastewater. The aluminum in PAX-18 is highly charged, enabling less of it to do more. Advantages available to many end users are Reduced Sludge, Minimized pH Adjustment, Longer Filter Runs, Superior Finished Water Quality, and Optimized Cold Water Performance. PAX-18 is a general-purpose coagulant, versatile enough to handle any type of challenge.

**PRODUCT SPECIFICATION**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Yellowish Liquid</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>9.0 ± 0.2%</td>
</tr>
<tr>
<td>$\text{Al}_2\text{O}_3$</td>
<td>17.1 ± 0.4%</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>&lt; 0.01%</td>
</tr>
<tr>
<td>Specific Gravity (25°C)</td>
<td>1.37 ± 0.03</td>
</tr>
<tr>
<td>pH</td>
<td>0.9 ± 0.3</td>
</tr>
<tr>
<td>Basicity</td>
<td>42 ± 2%</td>
</tr>
<tr>
<td>Active Material</td>
<td>3.33 moles/kg</td>
</tr>
<tr>
<td>Viscosity (25°C)</td>
<td>30 ± 5 cP</td>
</tr>
<tr>
<td>Freezing Point</td>
<td>-20°C / -4°F</td>
</tr>
</tbody>
</table>

**STORAGE**

Storage tanks and piping should be constructed of suitable non-corrosive material such as fiberglass or cross-linked polyethylene. PAX-18 is mildly corrosive and will attack most metals over a period of time. PAX-18 has a recommended shelf life of 8 months. As with any chemical, it is recommended to clean the storage tank every 1-2 years.

**HANDLING / SAFETY**

The handling of any chemical requires care. Anyone responsible for using or handling PAX-18 should familiarize themselves with the full safety precautions outlined in our Material Safety Data Sheet.

**DELIVERY**

55 gal. plastic drums / 275 gal. tote bin
Bulk tank trucks, Railcar
Corrosive Liquid, Acidic, Inorganic, n.o.s. 8, UN 3284, P.G. III

**PRODUCTION**

Kemira has coagulant production plants in

- Bartow, FL
- Fontana, CA
- Houston, TX
- Mojave, CA
- Rowley, UT
- Saint Louis, MO
- Savannah, GA
- Spokane, WA
- East Chicago, IN

**DOSSING**

PAX-18 should be fed straight without dilution. A diaphragm-metering pump of non-corrosive material is suitable.
Coagulant Dosing Calculations

• Goal: dose 0.1 mg Al/L of pool water.
• Conditions: Flow is 100 gpm, S.G. = 1.37, % Al is 9%.
  - Normally, 0.1 mg/L is 0.1 ppm, which means 0.1 mL per 1 million mL (or 0.1 mL per 1,000 L) or (0.1 mL per 264 gal)… in our case this would be 0.038 mL per 100 gal, which is also .038 mL/min per 100 gpm.
  - Now, we correct of % aluminum (since 91% of the solution is not aluminum) by dividing the 0.038 mL/min rate by 0.09, which becomes 0.42 mL/min.
  - Then, we correct for the density since we are delivering more actual mass than if the density was 1.00 (as assumed in the ppm conversion), so we divide 0.42 by 1.37, which yields a PACI feed rate of 0.31 mL/min per 100 gpm to achieve our goal of dosing 0.1 mg Al/L of pool water.
  - 0.31 mL/min of PAX Solution is 18 mL/hour (or 0.018 L/hr)
  - At this flow rate, a 55 gal drum would last ~482 days. We need a very small pump (and not much coagulant)!
  - You can simply scale this calculation in multiples of 100 gpm. For example, 588 gpm would require 5.88 times more coagulant (or 1.82 mL/min).
6. Amount of DE/Perlite Media

• Recommendation: use 1.5 lbs/10 ft² (0.73 kg/m²)
• Calculation: 50% more (or 1.5 times) the recommended Amount of DE
• Typically 1/8” +/-
• Perlite
  • Is Half the density of DE
  • Use same volume = half the weight (mass)
  • 0.73 kg/m² DE = 0.37 kg/m² Perlite (0.75 lbs/10 ft²)
Manufacturer Recommended Amount of DE filter media for different filter models

<table>
<thead>
<tr>
<th>Filter Area (sq. ft.)</th>
<th>Weight of D.E.</th>
<th>No. of 1 lb. Coffee Cans</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>2.4 lbs.</td>
<td>6</td>
</tr>
<tr>
<td>36</td>
<td>3.6 lbs.</td>
<td>8</td>
</tr>
<tr>
<td>48</td>
<td>4.8 lbs.</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>6.0 lbs.</td>
<td>12</td>
</tr>
</tbody>
</table>
DE Loading Rate Calculation

• Use rate = pounds of DE per ft$^2$ of filter area
• Use rate = 2.4 pounds of DE / 24 ft$^2$ of filter area = 1 lb/10 ft$^2$ (or 0.1 lb/ft$^2$) (or 10 lbs/100 ft$^2$)

• Coffee cans (fixed volume) allow you to hold the volume of media constant for media with different densities… while the weight varies.
Now that we know how to make filters work…

• How do we get the water to the filters?
3. Calculating theoretical detention time (or Turnover rate)

\[ \tau = \frac{V}{Q} = \frac{Volume}{Flow} = \frac{100,000 \text{ gal}}{500 \text{ gal/min}} = 200 \text{ min.} = 3.33 \text{ hrs.} \]

where:

\( V \) = pool volume (100,000 gallons)
\( Q \) = flow rate (500 gal/min)
\( \tau \) = theoretical detention time (turnover rate)
Let’s call this: “The Law of Dilution”

<table>
<thead>
<tr>
<th>Turnovers (t)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gage - Bidwell</td>
<td>63</td>
<td>86</td>
<td>95</td>
<td>98</td>
<td>99.3</td>
<td>99.7</td>
<td>99.99</td>
</tr>
<tr>
<td>Exponential Decay Model</td>
<td>63.2</td>
<td>86.4</td>
<td>95.0</td>
<td>98.2</td>
<td>99.3</td>
<td>99.7</td>
<td>99.995</td>
</tr>
</tbody>
</table>

Removal = 1 - e^{-t}

*where “e” is a constant (~2.718)*
Due to mixing inside of pools...

- Only 63% of the particles or pathogens get transported to the filter (and/or UV system) per turnover.
- So, a 99.9% efficient UV system can inactivate up to 63% of the Crypto in a pool per turnover (e.g., 6 hrs).
- Unfortunately, many pools filters are only about 25% efficient at removing Crypto. So, 25% of 63% is 15.8% of the total number of Crypto per 6 hrs.
- It is good to set the bar low to begin with! 15.8% removal per 6 hours is pretty low, wouldn’t you agree?
With a set hydraulic bottleneck (63%), how does treatment efficiency really impact things?

![Graph showing concentration of Cryptosporidium oocysts over time with different treatment system efficiencies (25%, 50%, 90%, 95%, 99%, 99.9%, 99.99%)](graph-url)
How long does it take to remove 99.9% of the *Crypto* in a pool?

\[ t_n = \frac{-\ln(1 - n)}{\alpha \tau} \]

where:

- \( t_n \) = time required to achieve desired contaminant removal fraction
- \( n \) = desired contaminant removal fraction
- \( \tau \) = theoretical detention time
- \( \alpha \) = treatment efficiency

Let's take a moment to put it all together…

How do you use all of this to produce a good design of a filtration/recirculation system?

• Hydraulic efficiency set by Gage-Bidwell in 1926 at 63% per pass.
• Filter efficiency improves contaminant removal drastically… up to about 90% removal efficiency.
• After getting filter efficiency to 90% or higher, the only SIGNIFICANT way to remove contaminants faster is to treat the water faster by reducing the turnover time (i.e., higher flows, higher energy bills, larger pipes, more pumps, more filters, etc.).
• Without proper operation and maintenance, you can make a relatively inefficient system much worse.
• Poor designs and cutting costs in the treatment room just ties everybody’s hands behind their back and ensures problems down the road.
Still have room to learn some more? Try these:

• Vacuum sand filters can air bind very easily.
• The wrong paint, coating, or surface preparations can lead to misery.
• Sand can last at least 40-50 years if properly cleaned and maintained.
• High hardness, high pH, or high mineral content can lead to the sand in the filters being “cemented” or “becoming sandstone”.
• Avoid excessive clothing fibers or paper towels in the pool. Some things will NOT backwash out.
• Inadequate backwash rates are the rule (not the exception)… frequent backwashes & a cloudy pool are good co-indicators of this problem.
• Neglected or under-designed filters WILL find a way to get your attention!
Take Home Message!

• Without proper design & coagulation, research indicates that sand filters are not a very efficient barrier against *Cryptosporidium*.
• Backwashing is crucial to sand filters.
• Precoat filters are more effective with the proper amount of media & avoiding flow interruption.
• New options like Ultrafine Ceramic Sand & Ceramic Membranes are on the horizon… but might never get here without YOUR help.
• If you don’t change, then neither will any of the major problems we are facing in Aquatics!
• Nothing will work, unless you do.
Thank you so much attending!

What Questions do you have?
Final slide reserved for conference marketing purposes