REINHOLD ENVIRONMENTAL ®

2025 Reinhold/PCUG Round Table Presentation

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VISTRA

Wastewater Treatment 101

A ‘First Principles’ Approach

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Overview

Design parameters to consider:

- Environmental limits & other constraints
- Influent chemistry
- Flow expectations & consistency
- Design footprint & siting
- Robustness expectations

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Overview

- Typical wastewater controls in power plants include:
  - –pH Control
  - –Solids (TSS) control:
    - Sedimentation
    - Clarification
    - Filtration
    - Coagulation & flocculation
  - –Dissolved solids (TDS) control:
    - Softening
    - Metal Precipitation
    - Reverse Osmosis
    - Ion Exchange
  - –Biological Treatment
  - –Oxidation & Dechlorination

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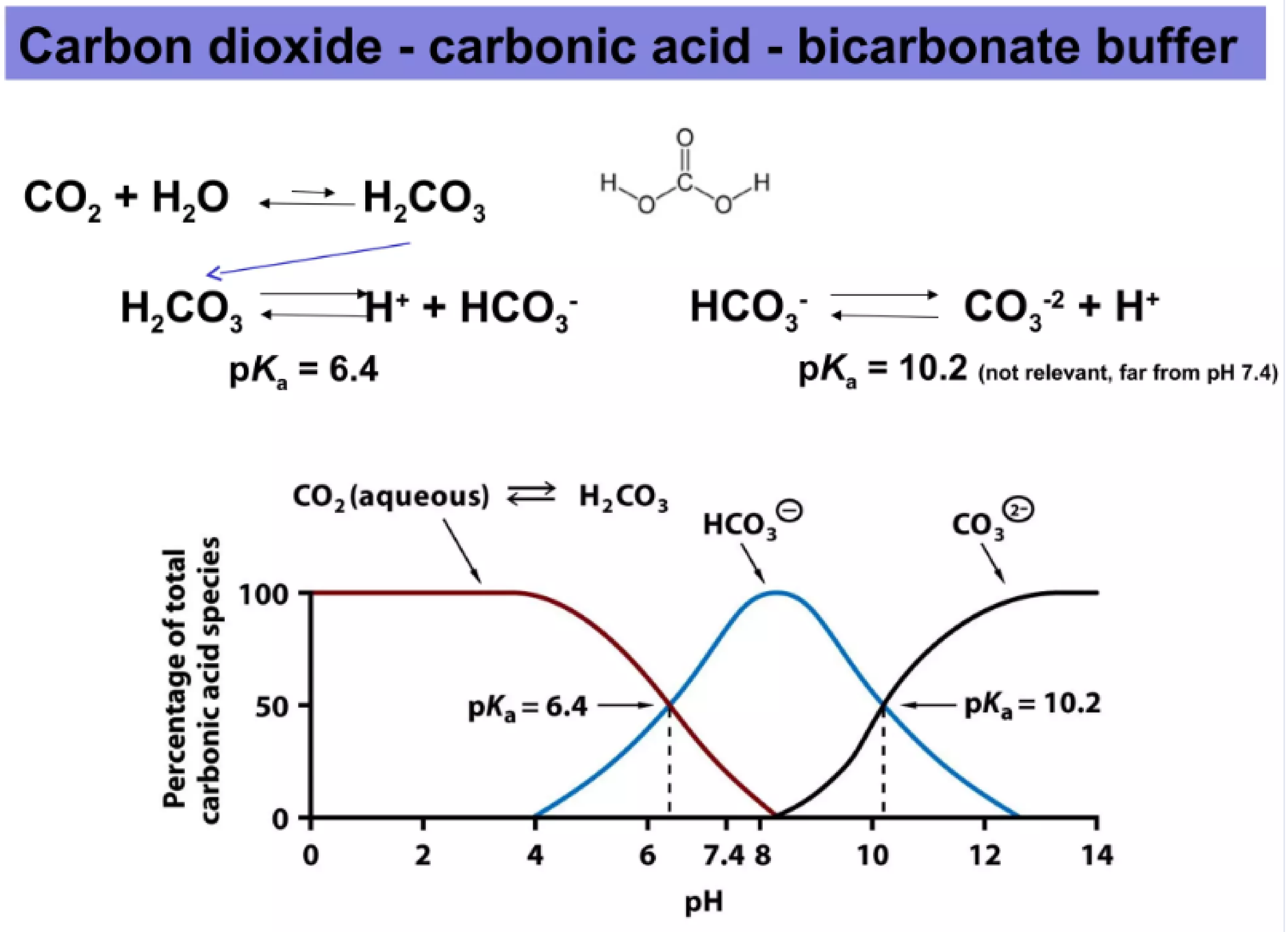
pH Control

- Depending on upstream processes, wastewater can be acidic (low pH) or alkaline (high pH)
- Typical receiving water pH of 7-8, with discharge limits commonly mandating a 6 or 6.5 to 9 pH at the outfall
- To raise pH:
  - –Addition of a caustic compound, typically:
    - Sodium hydroxide (caustic soda – $NaOH$)
    - Calcium hydroxide (lime – $Ca(OH)_2$)
    - Sodium bicarbonate (baking soda – $NaHCO_3$)
- To lower pH:
  - –Addition of an acidic compound, typically:
    - Sulfuric acid (H_2SO_4)
    - Hydrochloric acid (muriatic acid – HCl)
    - Carbon dioxide (CO_2) – bubbled in as a gas, forms carbonic acid (H_2CO_3) in water
- Process can be automated by adding online pH measurement downstream and adjusting chemical feed

Alkalinity, Buffering & Le Chatelier's Principle

- Wastewater alkalinity impacts pH control
- Alkalinity: The capacity of water to neutralize acids and resist pH changes
  - –Typically influenced by carbonates, bicarbonates, and hydroxides present
  - –Determined by titrating the water with a strong monoprotic acid to an acidic endpoint (pH 3)
- Higher alkalinity streams will require more acid or base to adjust pH



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TSS Control

- Total suspended solids are precipitated solids that do not pass through a 0.45-micron filter
  - Typically, these are process materials, including:
    - Silt or sand from incoming makeup water
    - Process solids, such as FGD slurry remnants, gypsum, or ash
    - Previously dissolved solids that were precipitated out
    - Biosolids, such as algae
  - TSS limits are typically 15-30 ppm in an NPDES outfall

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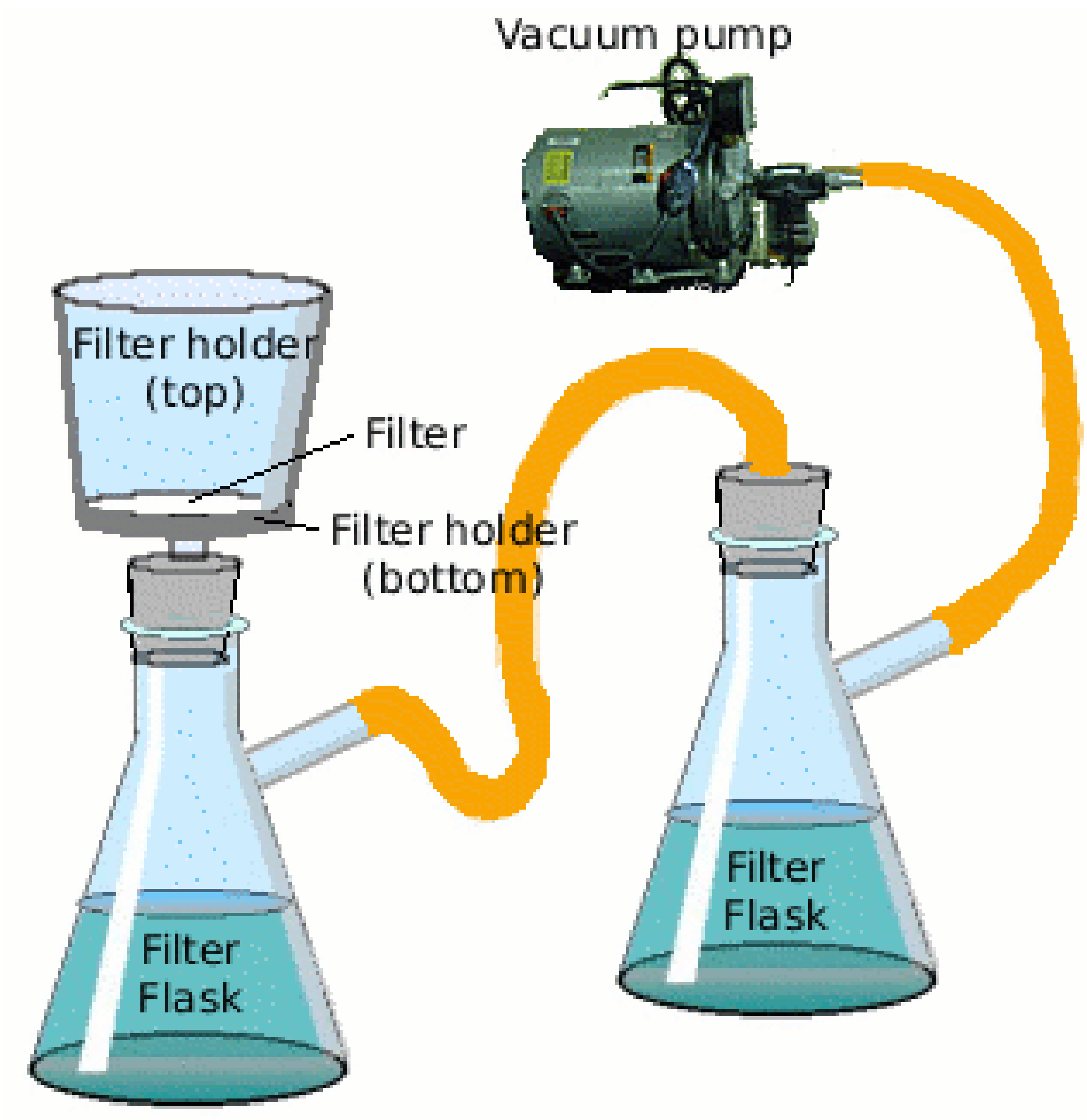
TSS Measurement

- TSS is measured as a concentration, typically ppm (or mg/L)
- A sample is agitated and passed through a pre-weighed 0.45-micron filter
  - –A vacuum pump or aspirator is typically used with a filter flask to speed the process
- The filter is dried and weighed again to calculate the mass of filtered solids and compared with the volume of sample



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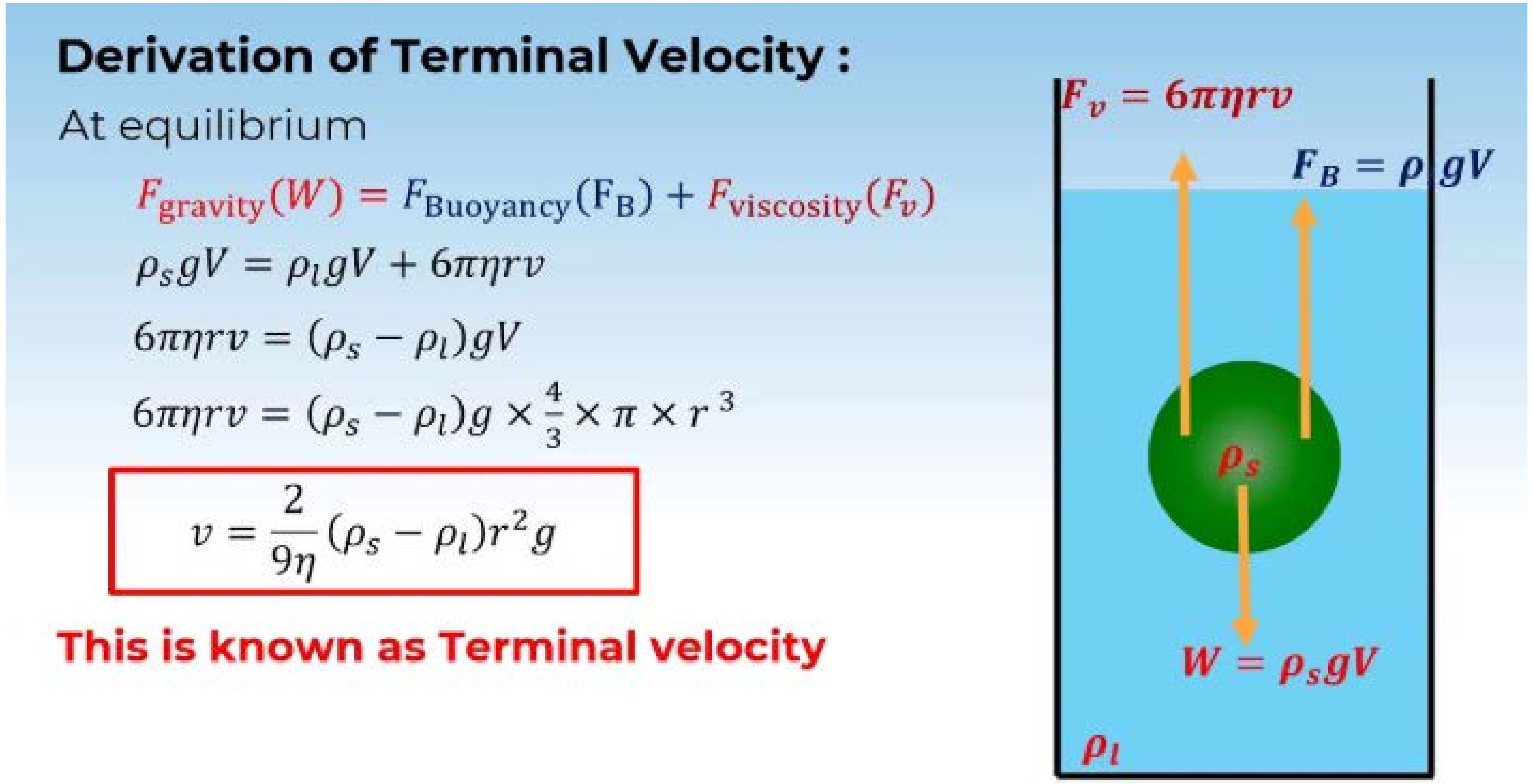
Sedimentation/Settling – Stoke's Law

- Given enough time, all particles over a certain size will settle due to gravity
- Settling rate influenced by:
  - –Particle size
  - –Particle Shape
  - –Particle Density
  - –Fluid Density
  - –Fluid Viscosity



- Main controllable factors:
  - –Particle size & density

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Particle Size and Settling Velocity

- Controlling particle size is the most straightforward means of improving settling velocity:

Relative Settling Velocities vs. other particles in STILL water

Particle Size (mm)	Order of Magnitude	Time Required to Settle 1 Foot
10.0	Gravel	0.3 Seconds
1.0	Coarse Sand	3 Seconds
0.1	Fine Sand	38 Seconds
0.01	Silt	33 Minutes
0.001	Bacteria	35 Hours
0.0001	Clay Particles	230 Days
0.00001	Colloidal Particles	6.3 Years

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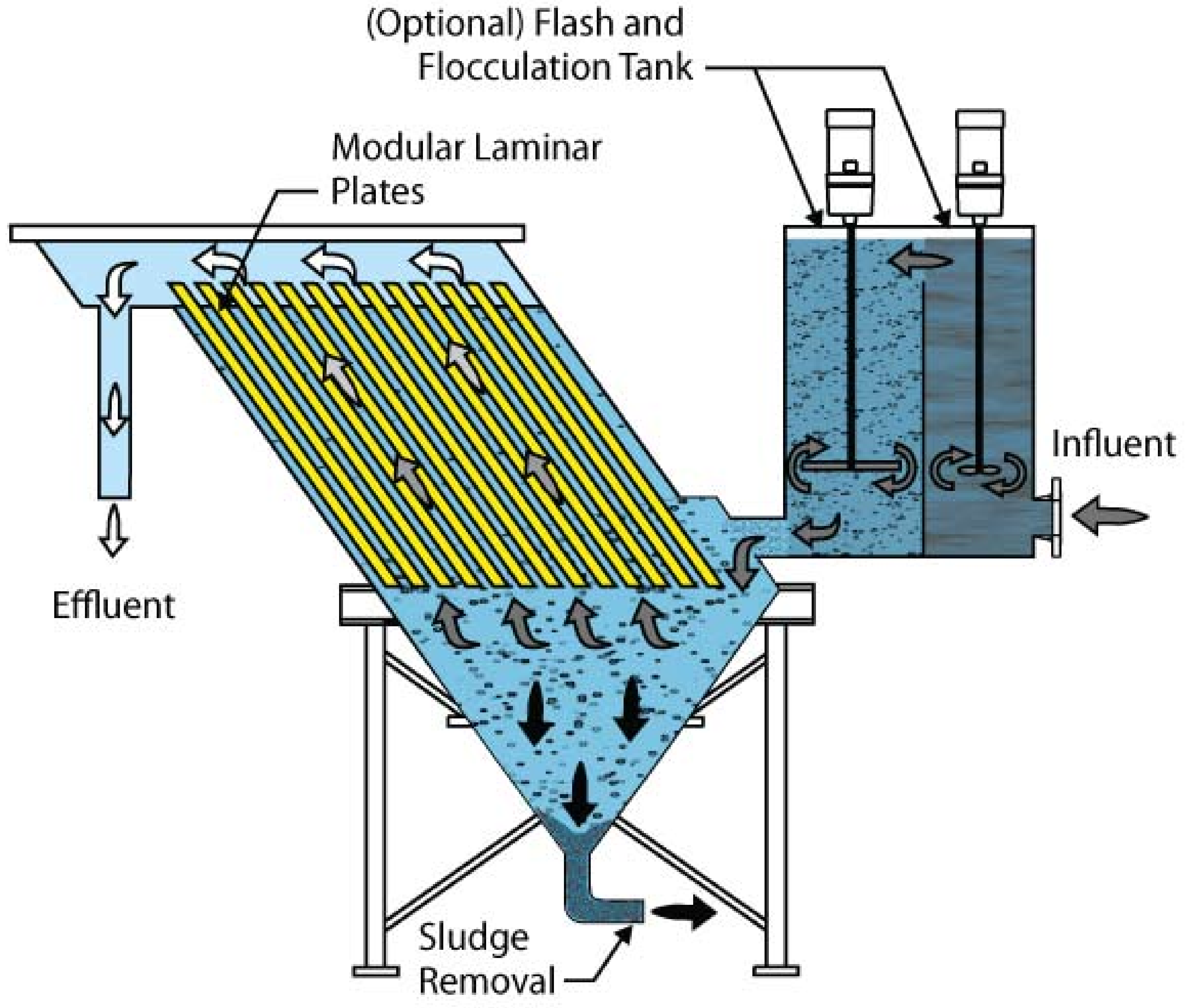
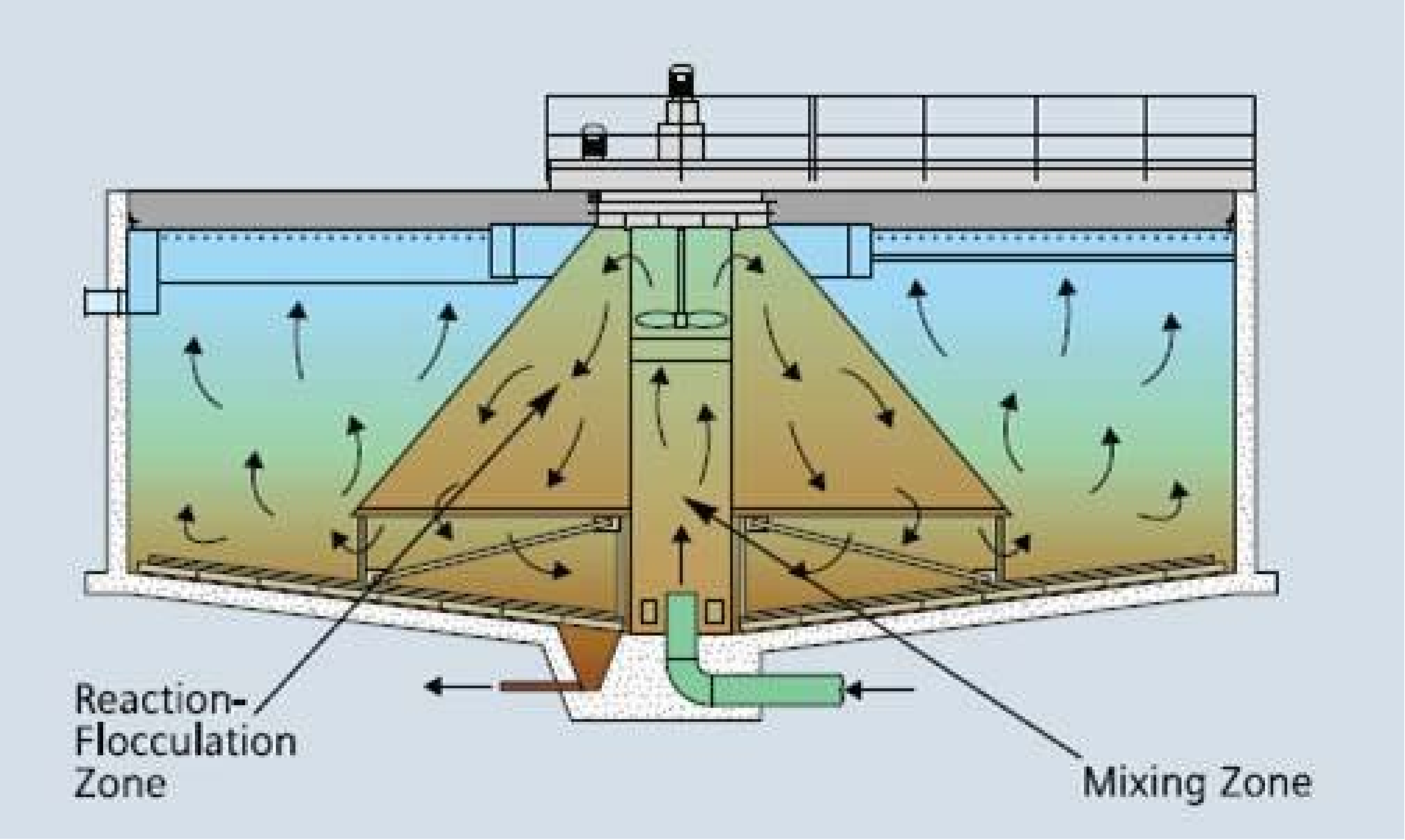
Clarification

- Clarifiers use the principles of sedimentation within mechanical systems
- Various types:
  - –Conventional
  - –Solids Contact
  - –Inclined Plate





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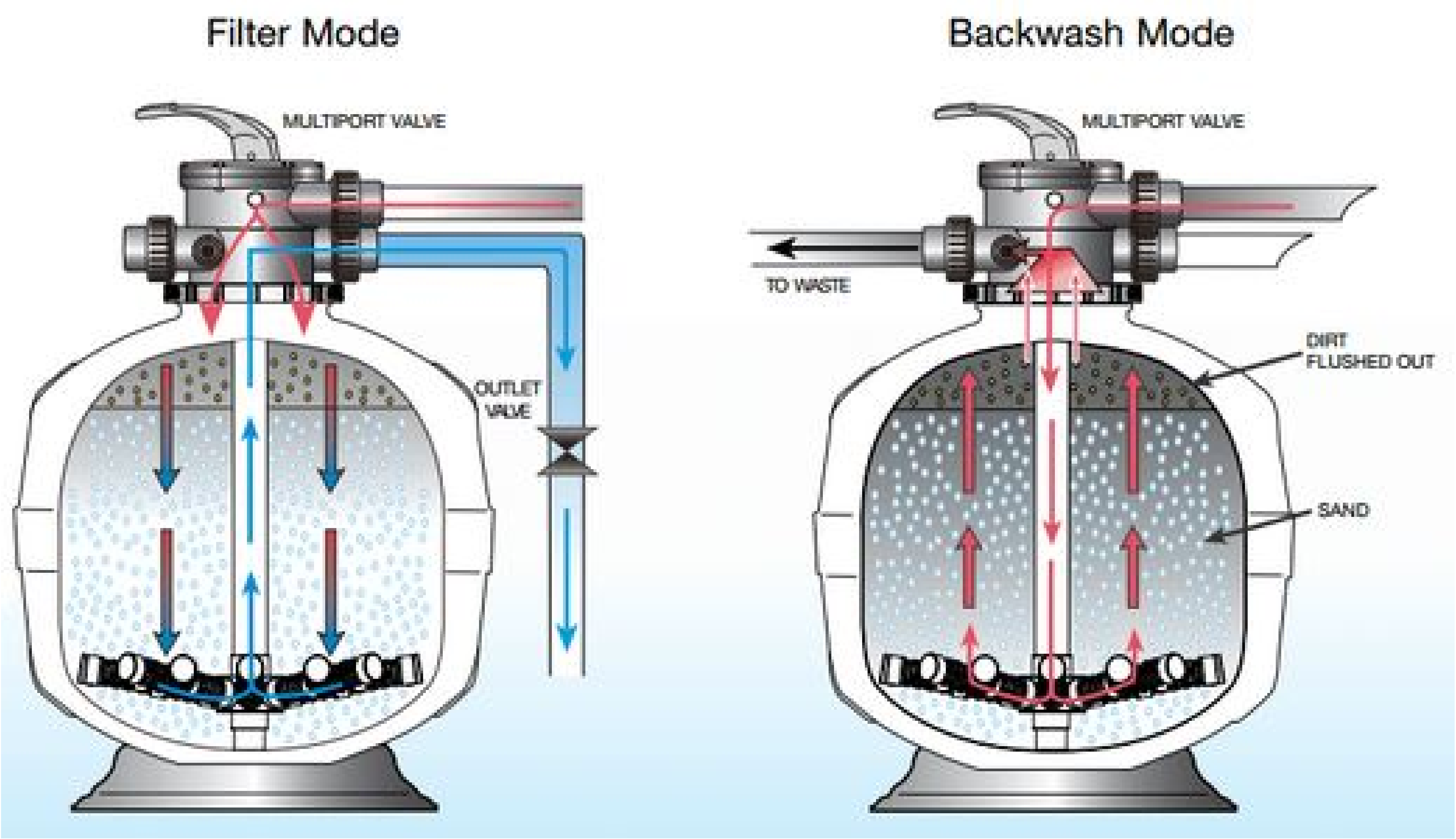
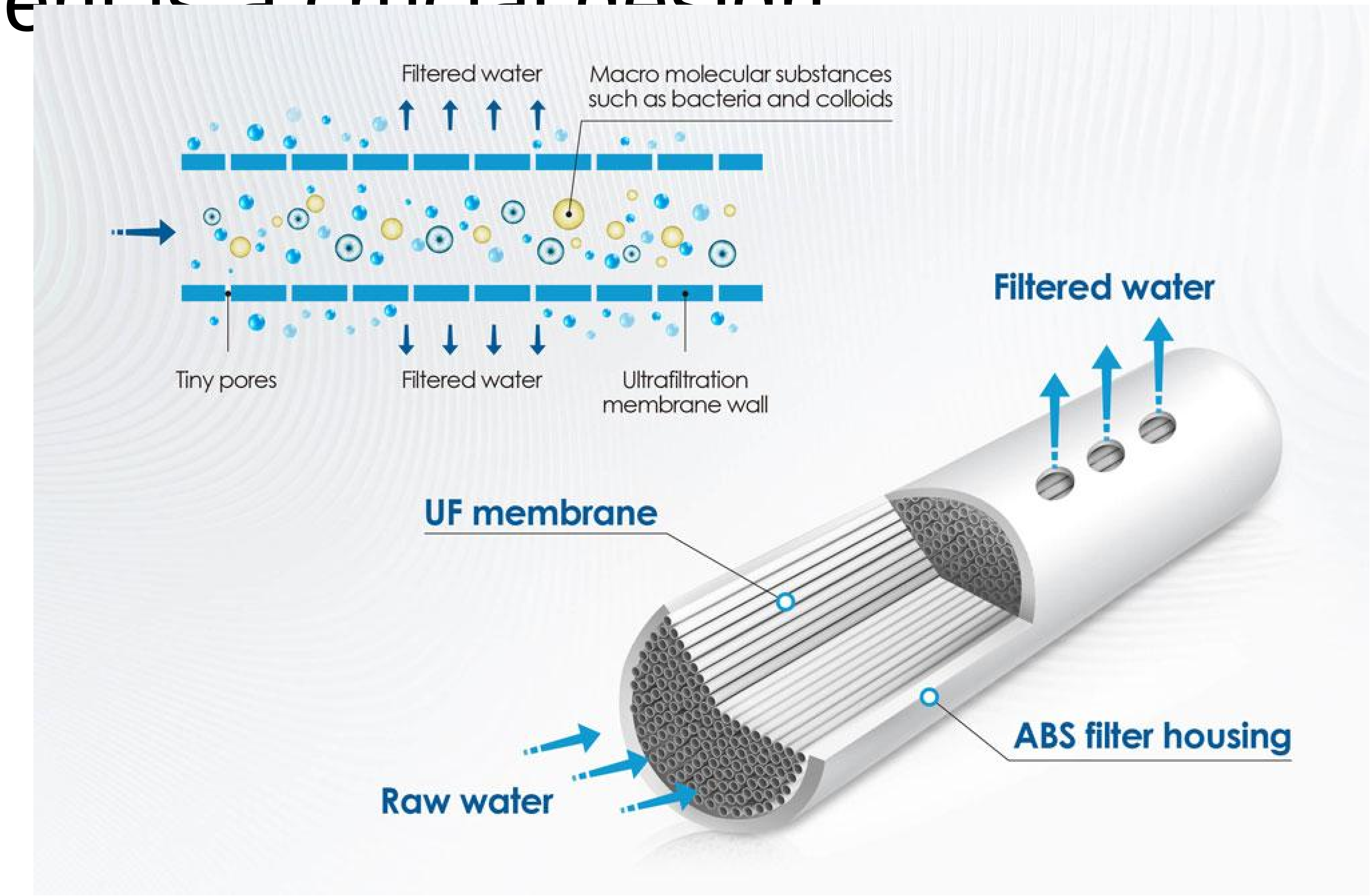
Clarification Solids Management

- Clarifiers allow for intermittent or continuous removal of solids in the underflow
  - Solids management is crucial for clarifier operation
- Solids are typically thickened in a filter press, belt press, or dewatering drum
  - Improved thickening (% solids) will reduce waste disposal costs and simplify handling

Filtration

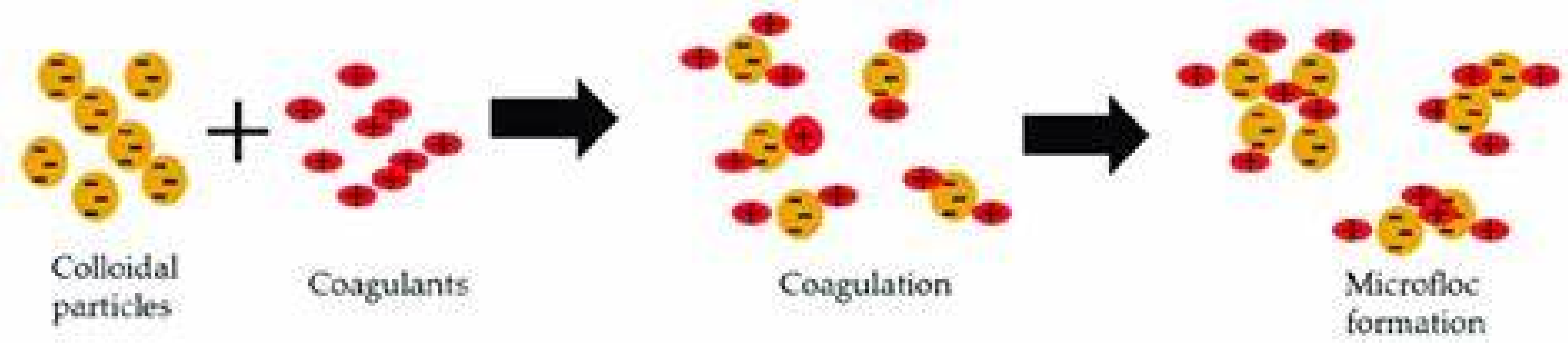
- Various types of filtration can be used to assuredly remove particles of a given size
- Filter cake solids and backwashing management is a crucial design





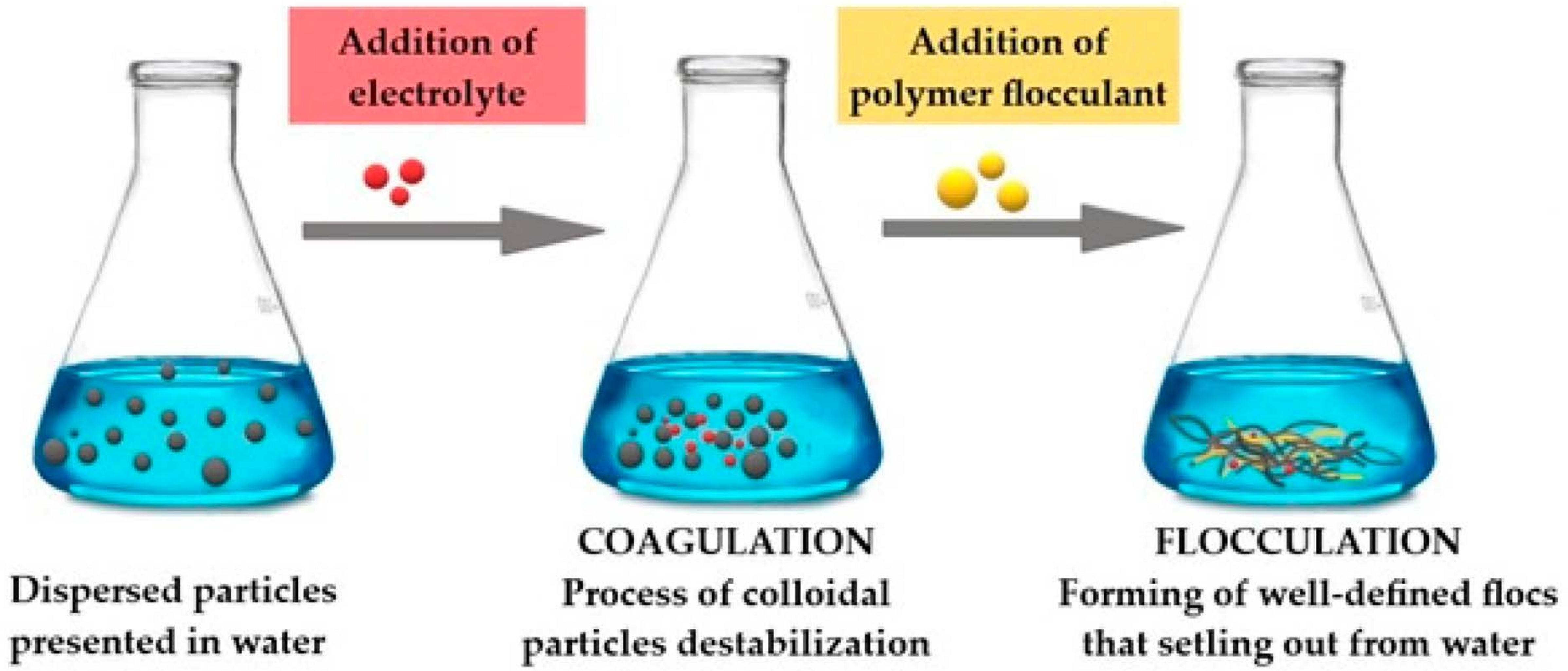
Coagulation

- Colloidal particles (typically < 1 micron) will not efficiently settle due to their size and are difficult to filter
- Surface charges prevent attractive van der Waals forces from allowing particles to combine, allowing these small particles to remain stable and suspended
- Coagulants neutralize the surface charge on the colloidal particles
  - The weak van der Waals forces then are strong enough to allow particles to interact and aggregate into larger particles

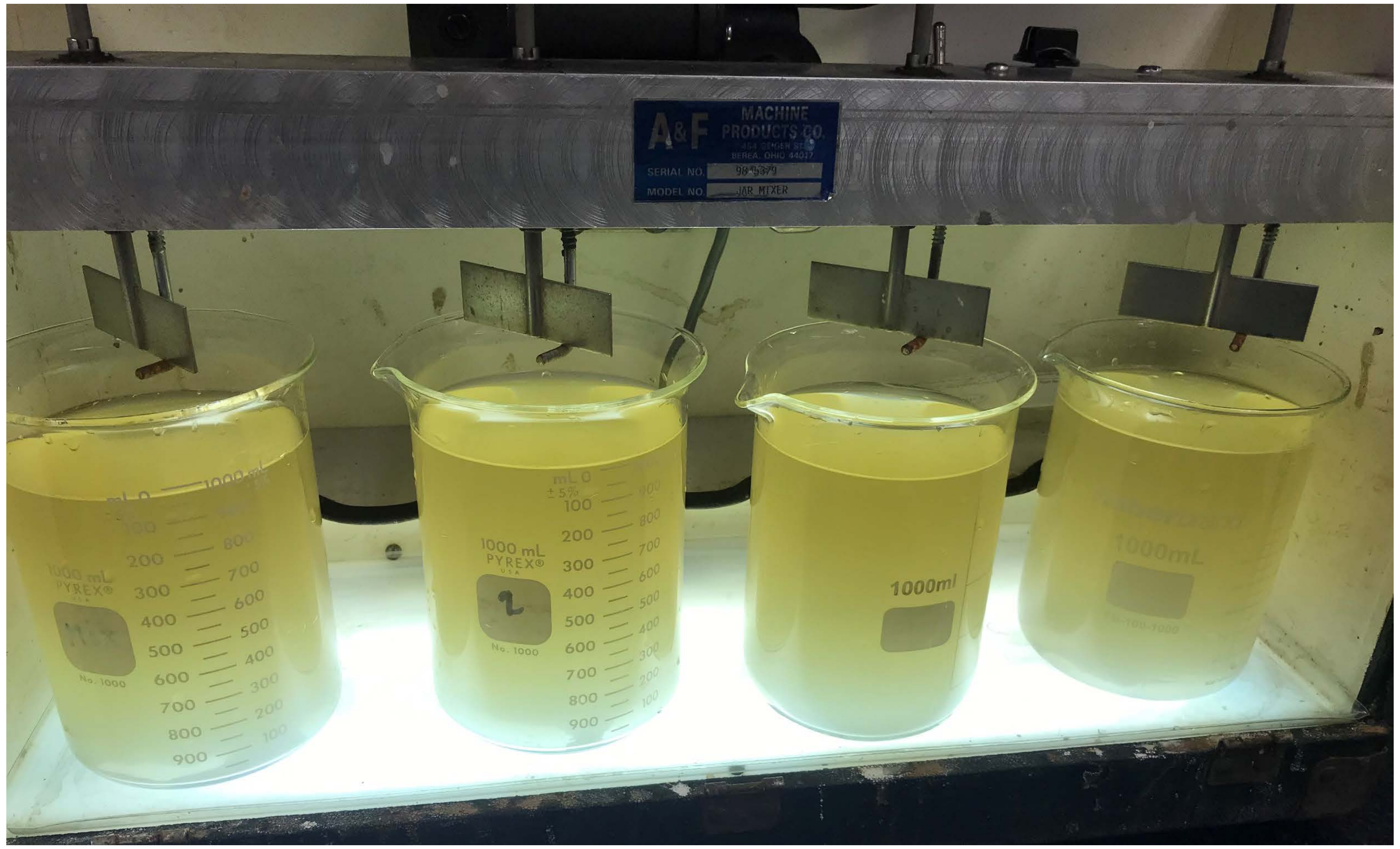


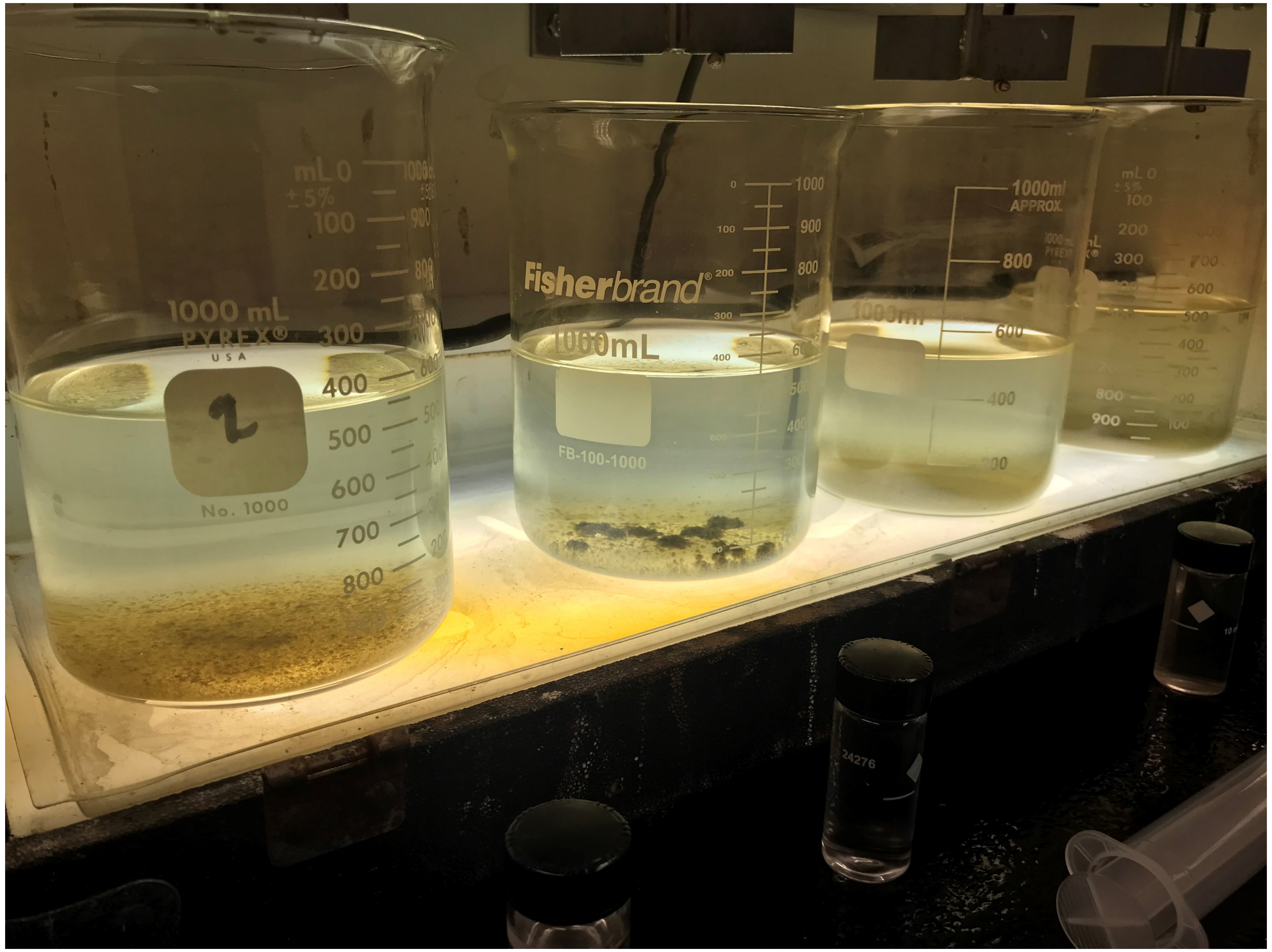
Flocculation

- Coagulant-neutralized particles are often still extremely small, and reliance on existing interactions can take excessively long to clarify the water
- Introduction of a polymeric flocculant (typically polyacrylamides) can allow the neutralized particles to clump (agglomerate) together.
  - Flocculant is typically introduced downstream of the coagulant and after aggressive mixing



Jar Testing


A&F MACHINE PRODUCTS CO.
SERIAL NO
MODEL NO
JAR MIXER
1000 mL PYREX®
1000ml


1000 mL PYREX®
No. 1000
Fisherbrand®
FB-100-1000
1000ml APPROX.

Dissolved Solids Control

- Dissolved solids are compounds in water that pass through a filter
  - –Typically, dissolved salts but can include some organics
  - –Often monitored or limited in wastewater permits:
    - Total dissolved solids (TDS)
    - Specific ions such as chloride, fluoride, sulfate, boron
    - Toxicity (excessive TDS in a stream can impact toxicity)

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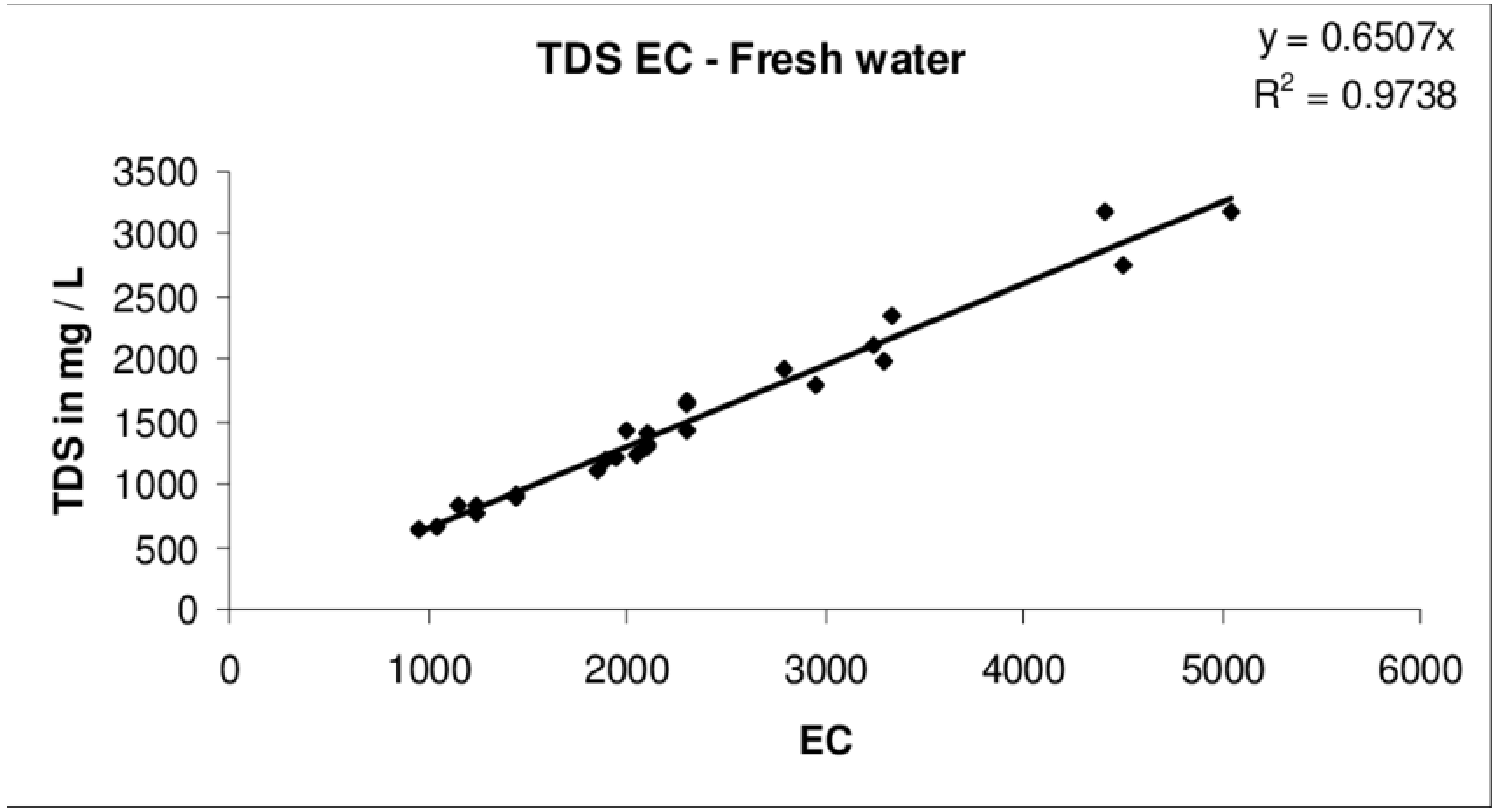
Dissolved Solids Measurement

- TDS is typically measured by filtering a sample and then evaporating to dryness
  - –The weight of solids in the filtrate relative to the total sample weight/volume
  - –Reported in parts per million (ppm) or mg/L
- TDS is also typically measured in surrogate as sample conductivity (uS/cm)
  - –Conductivity is proportional to TDS for a given species of salt
  - –Correlation curves between the two can be made to estimate online
  - –Conductivity can be strongly temperature dependent, TDS less so (density changes)



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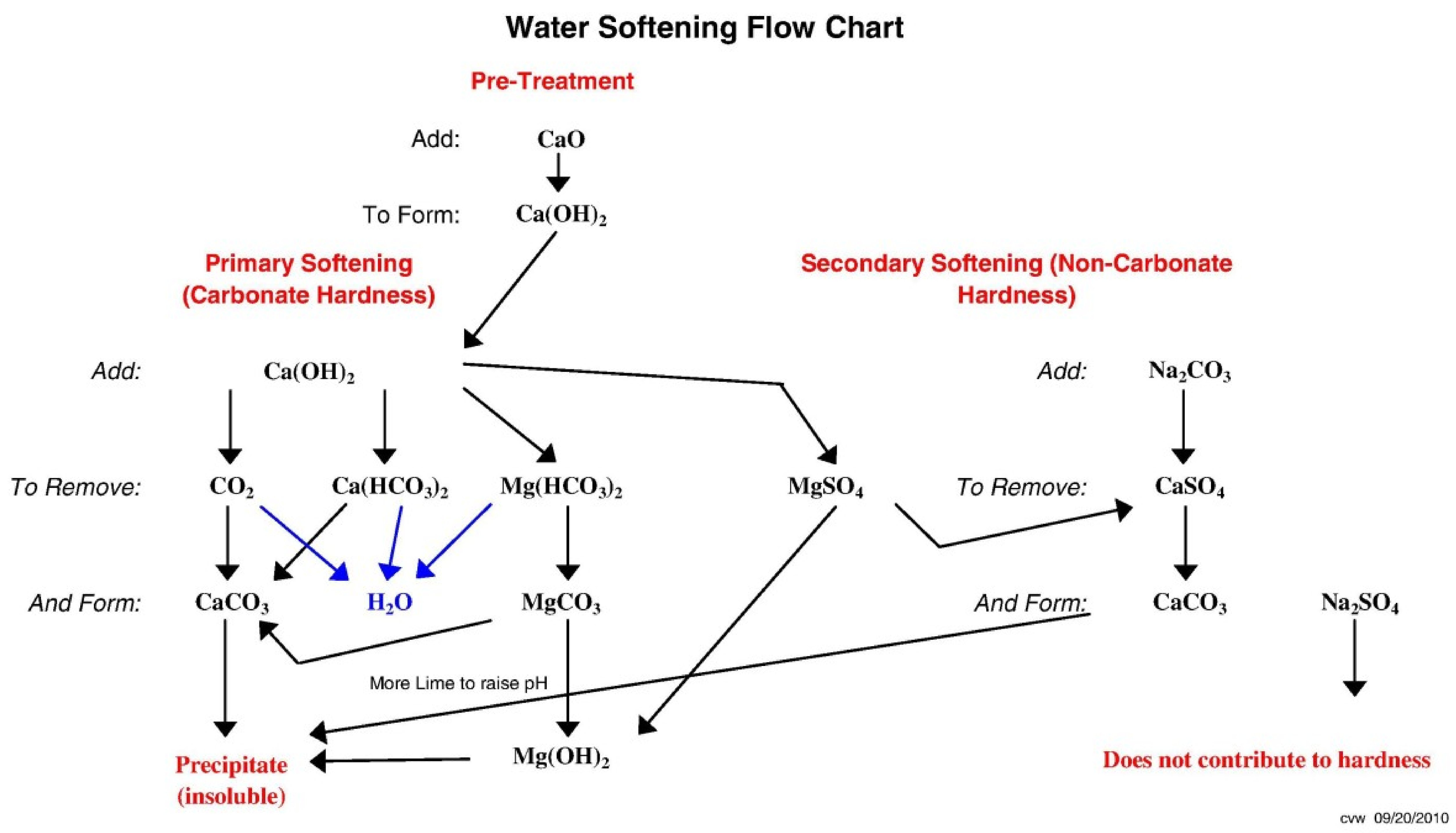
TDS Treatment: Softening

- Sulfate and carbonate compounds present in wastewater can be precipitated out with the addition of calcium (lime or limestone)
  - –Calcium sulfate (gypsum) & calcium carbonate precipitation – conversion to a suspended solid to be settled or clarified out
  - –Elevates pH, may require re-acidification to neutralize
  - –If pH elevates significantly – 10+, hydroxides ($Mg(OH)_2$ or metal hydroxides can also precipitate
  - –Use of sodium carbonate (washing soda) can precipitate calcium carbonates to reduce dissolved calcium



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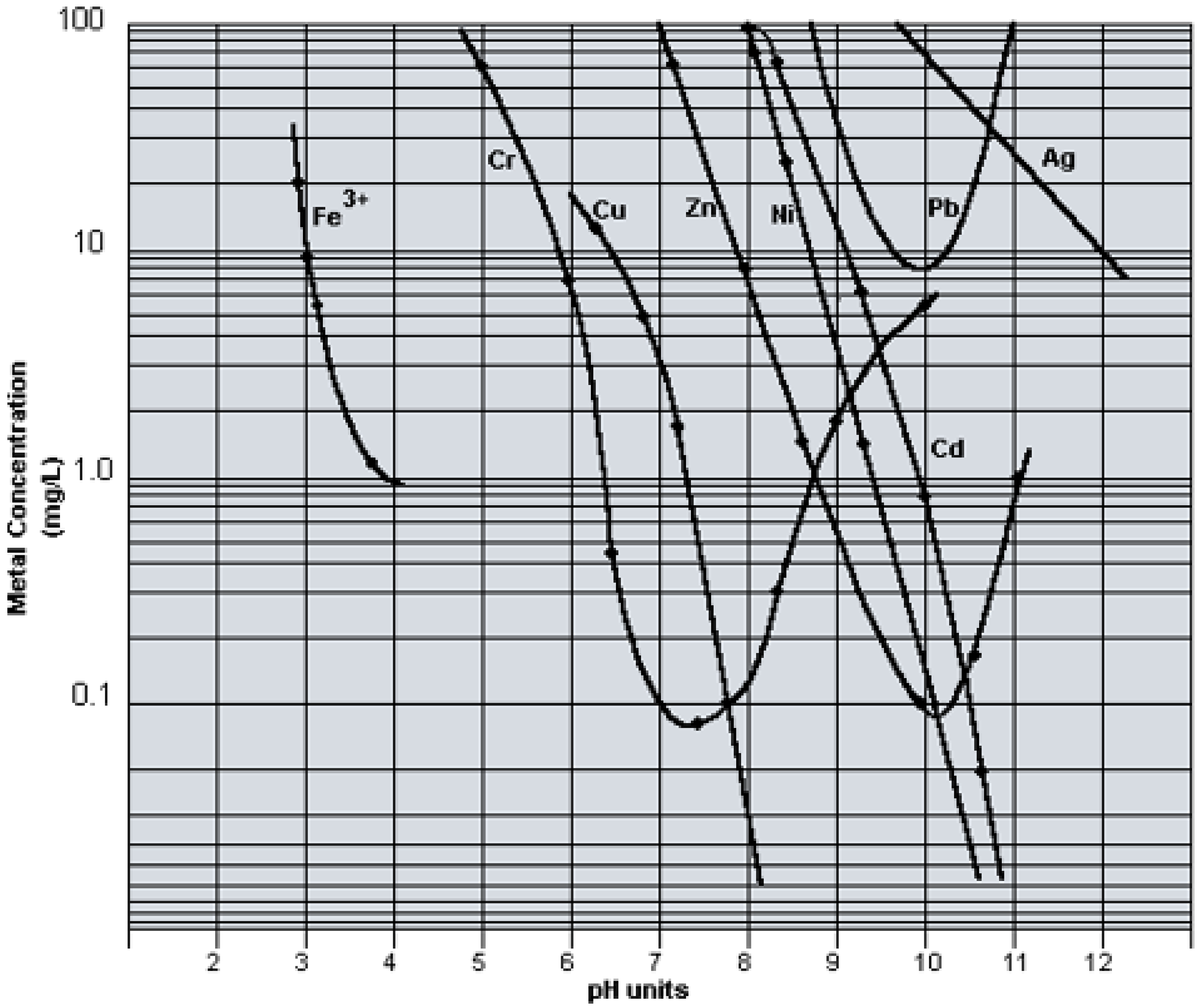
TDS Treatment: Metal Hydroxide Precipitation

- Metal hydroxide precipitation:
  - –Addition of lime or caustic to raise pH
  - –Very effective for iron and to a lesser degree copper
  - –Some metals exhibit increasing solubility at alkaline pH (Cr)
  - –To meet discharge pH requirements, re-acidification after solids separation may be required (expensive)



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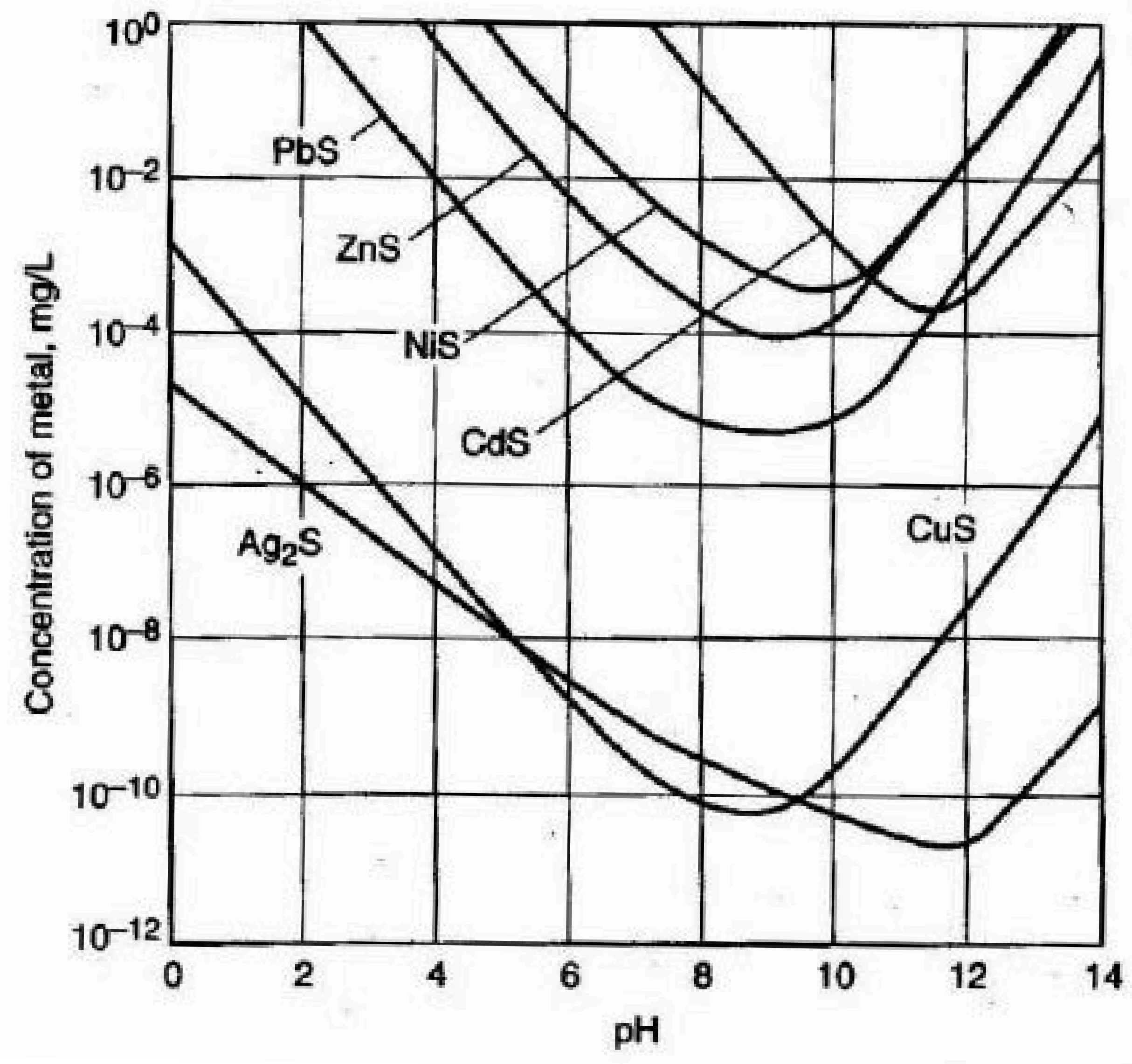
TDS Treatment: Sulfide Precipitation

- Metal sulfides are typically insoluble, so the introduction of an inorganic or organosulfide compound.
- Strong performance at neutral or slightly alkaline pH is possible, typically not requiring acidification.
- Specialty products are designed to help coagulate precipitated species and can selectively precipitate ions.
- Dosage is typically low (ppm level), but products can elevate toxicity if overfed

FIGURE: PRECIPITATION OF HEAVY METAL w.r.t. pH (METCALF ET AL. 2003)



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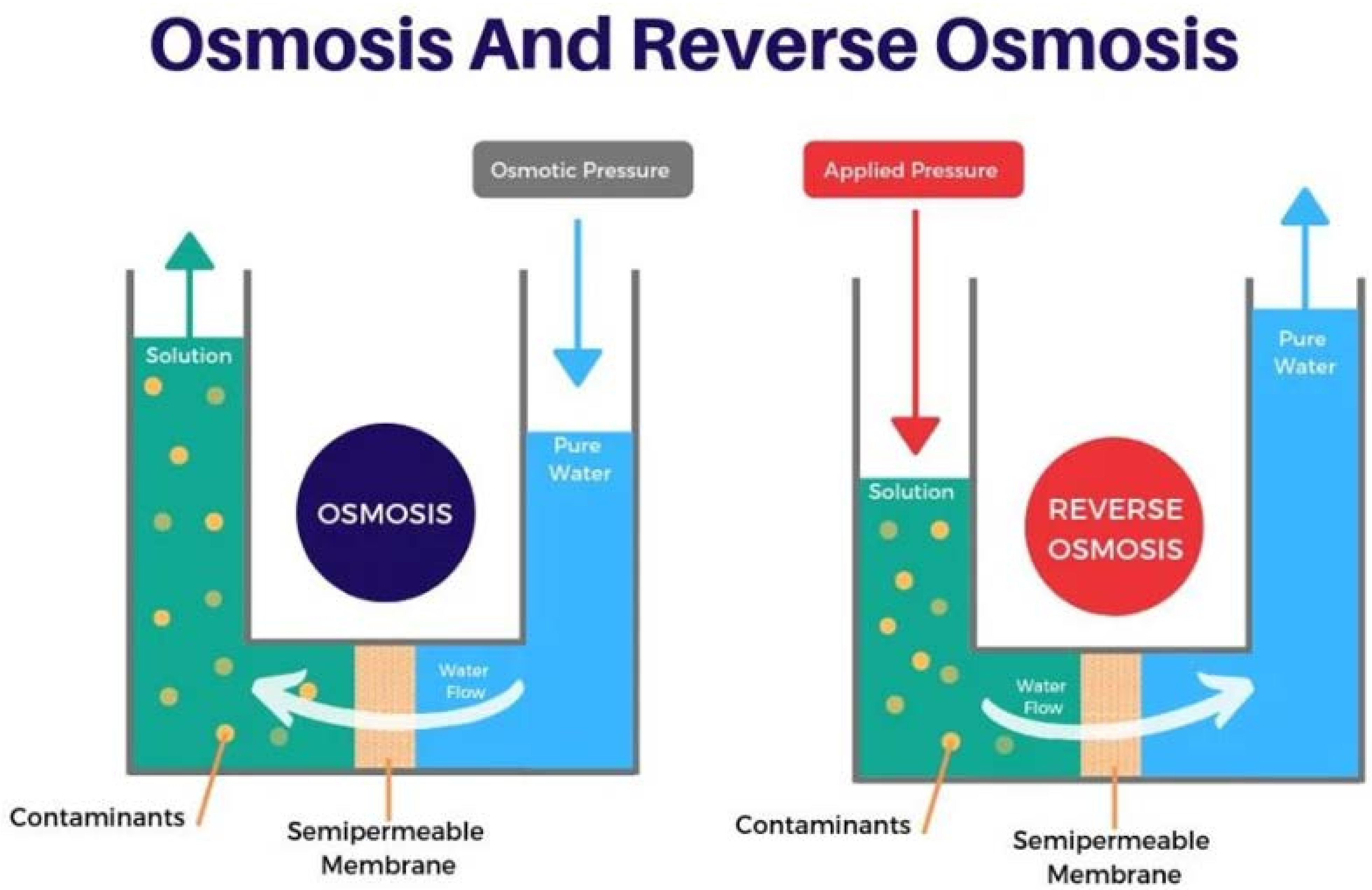
TDS Treatment: Reverse Osmosis

- Reverse Osmosis: Modern workhorse of TDS removal
  - –Osmosis: Passage of water through a semi-permeable membrane from a region of lower to higher ion concentration
  - –Reverse Osmosis: Under pressure, water can be forced through a membrane from a region of higher to lower ion concentration, thus producing a low TDS permeate stream.
  - –Removal of highly soluble ions (Na^+, Cl^-, etc)
  - –A continuous reject stream is produced with elevated TDS, must be managed
  - –Operational challenges: pH control, biofouling control, scale control, power consumption



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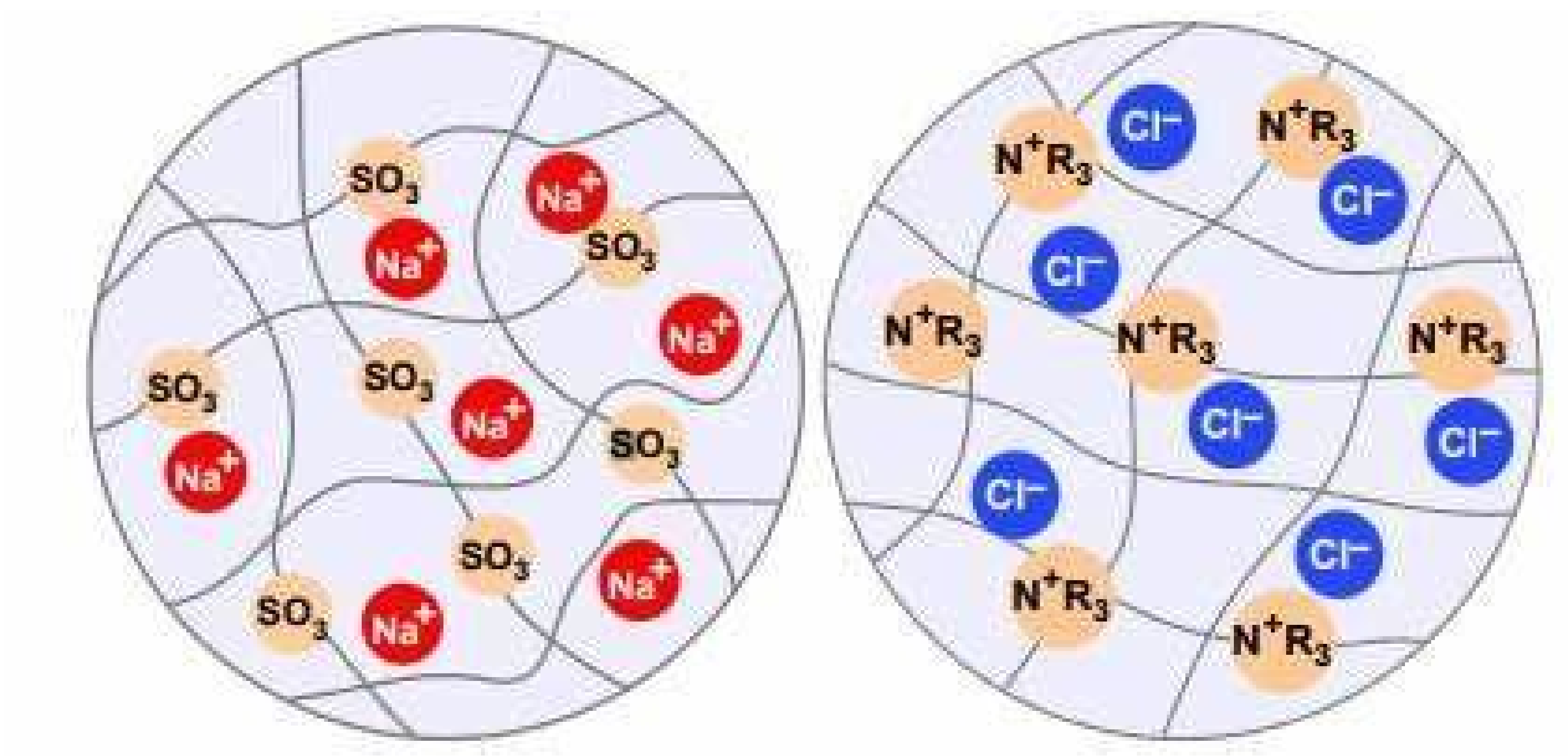
TDS Treatment: Ion Exchange

- Ion exchange resin can replace undesirable ions with more desirable ones:
  - –Cation: H^+ or Na^+ for Ca^{2+}, Mg^{2+}, metals
  - –Anion: OH^- or Cl^- for SiO_2, SO_4^{2-}
  - –Specialized resins exist for boron, nitrate, etc.
- Regeneration or disposal must occur once the resin is saturated with undesirable ions (spent)
  - –Regeneration will produce a concentrated waste stream, for potential alternative treatment
  - –Disposal will generate a solid (potentially hazardous) waste



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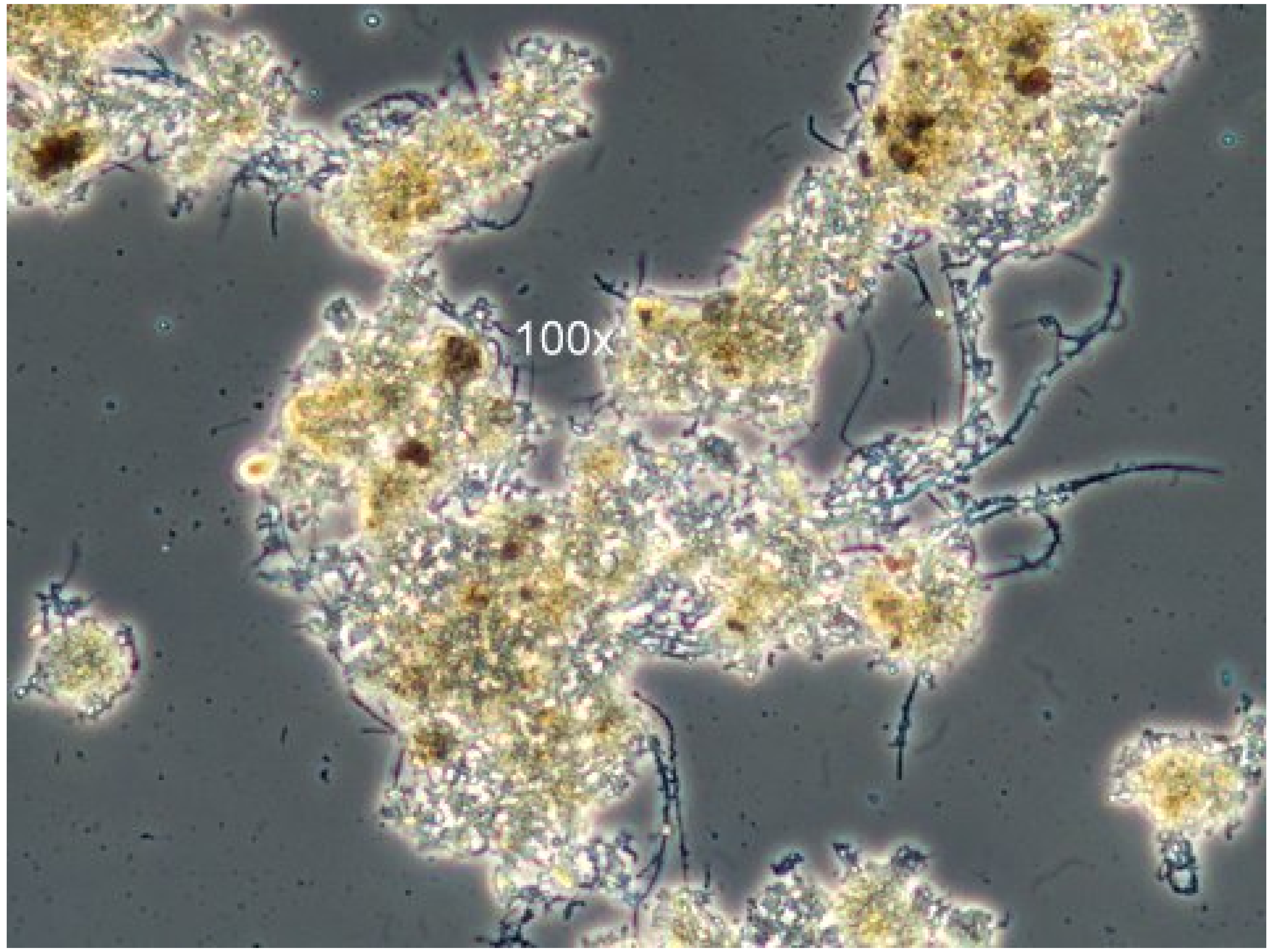
Biological Treatment

- Microbes added to wastewater can support biological processes, typically oxidation or reduction of components in wastewater
- Generally, these organisms interact with organics and nitrogen-based compounds
- The presence or absence of oxygen generally determines the type of organisms present and their means of operation
- These microbial systems are commonly used to treat sewage but also notably can reduce oxidized selenate species to selenite, allowing for precipitation and removal as TSS



Oxidation & Dechlorination

- Oxidation can mitigate some organics to CO_2 and sulfides to sulfite/sulfate.
- Oxidizers must be fed stoichiometrically. Competing reactions often require overfeed to achieve desired results.
- Oxidizers are typically toxic, so a reducing agent like sodium sulfide or a binding agent like bentonite clay can be fed after treatment to destroy residual oxidant.

Compound	Formula	ORP (V)
Hydroxide radical	$OH\cdot$	2.80
Ozone	O_3	2.07
Hydrogen peroxide	H_2O_2	1.78
Chlorine dioxide	ClO_2	1.57
Hypochlorous acid	HOCl	1.49
Chlorine	Cl_2	1.36
Hypochlorite	OCl^-	0.94
Monochloramine	NH_2Cl	0.75

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Conclusion

- The basic principles discussed govern much of the wastewater treatment space in the industry.
- Modern technology has improved efficiency, energy use, and size requirements of these processes but sometimes presents additional risk and cost
- A strong understanding of input conditions and output requirements will help ensure system success
- The value of mechanical systems and chemical enhancements will generally create the most valuable solution