Low Level Phosphorus Removal – Facts and Figures

Wisconsin Wastewater Operators Association

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Wisconsin's Phosphorus Water Quality Standards

- Effective December 1, 2010
- NR 102 – Water Quality Criteria
- NR 217 – Effluent Limits for WPDES Permits

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Water Quality Standards

- Larger Rivers – 100 µg/l
- All Other Rivers – 75 µg/l
- Lakes/Reservoirs – 15 – 40 µg/l

Effluent Limits

- WWTPs on Larger Rivers – 100 µg/l
- WWTPs on Streams – 75 µg/l
- Potentially Higher Where Background Water Quality Allows

Alternatives to Meet Water Quality Based Effluent Limits

- Construction to Meet Effluent Limits
- Adaptive Management
- Water Quality Trading
- Economic Variance
- Multi-Discharger Variance

Look at Typical Activated Sludge Plant

- 1.0 MGD
- 6 mg/l P influent (50 lbs/day)
- 250 mg/l BOD_5 Influent (2,085 lbs/day)
- No Primary Clarifier
- Activated Sludge
- Final Clarifier

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Look at Typical Activated Sludge Plant

- Combination Biological Phosphorus Removal/Chemical Phosphorus Removal
- P Effluent Averages 0.7 mg/l (700 µg/l)
- Effluent BOD_5 = 10 mg/l
- TSS Effluent Averages 10 mg/l

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Look at Typical Activated Sludge Plant

- Total Aeration Tank Volume – 1.0 Million Gallons
- MLSS = 2,400 mg/l
- MLVSS = 1,680 mg/l (70% of MLSS)
- Mass of MLVSS = 14,011 lbs
- Influent BOD_5 Mass = 2,085 lbs
- F:M = 2,085/14,011 = 0.15

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Look at Typical Activated Sludge Plant

- Sludge Production = 75% of Influent BOD_5
- Waste Sludge to Solids Handling = 1,480 lbs/day
- TSS Discharged = 83 lbs/day
- Total Solids Lost = 1,564 lbs/day

Look at Typical Activated Sludge Plant

- Mean Cell Residence Time
  - Aeration Plus 40% Final Clarifier = 1.2 Million Gallons
  - MLSS = 2,400 mg/l = 24,019 lbs
  - Total Waste Sludge = 1,564 lbs/day
  - MCRT = (24,019/1,564) = 15.0 days

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Look at Typical Activated Sludge Plant

- Phosphorus in Effluent (0.7 mg/l) = 5.8 lbs/day
- Phosphorus Removed in WAS = 44.2 lbs/day
- Phosphorus % in WAS = 44.2/1,480 = 3.0%

Look at Typical Activated Sludge Plant

- Phosphorus in Effluent (0.7 mg/l) = 5.8 lbs/day
- Particulate P (3.0% of MLSS) in Effluent = 2.5 lbs/day (0.3 mg/l)
- Soluble P in Effluent = 5.8 - 2.5 = 3.3 lbs/day (0.4 mg/l)
- P Removal = 88%

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Optimize the Process

- Reduce Soluble P in Effluent to 0.1 mg/l
  - Higher Chemical Dosage
- Reduce Effluent TSS to 5 mg/l
  - Add Polymer

Optimize the Process

- Soluble P in Effluent = 0.1 mg/l
- Particulate P (3.2% of MLSS) in Effluent = 5 mg/l TSS x 8.34 x 1.0 = 41.7 lbs TSS/day

  41.7 x 0.032 = 1.33 lbs/day P in Effluent

  1.33/8.34/1.0 = 0.159 mg/l Particulate P
- Total P in Effluent = 0.1 + 0.159 = 0.259 mg/l
- P Removal = 96%

Optimize the Process

- Optimization Alone Cannot Meet Effluent Limit of 0.1 or 0.075 mg/l P

How To Meet 75 µg/l (0.075 mg/l)

- Need to Reduce Soluble P to 0.02 mg/l
- Need to Reduce Particulate P to 0.05 mg/l
- Total Effluent P = 0.07mg/l = 0.58 lbs/day
- P in Waste Sludge = 49.4 lbs/day
- Total P Out = 50 lbs/day
- P Removal = 99%

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How To Meet 75 µg/l

- Sludge Production = 75% of Influent BOD_5
- Waste Sludge to Solids Handling = 1,480 lbs/day
- P in Waste Sludge = 49.4 lbs/day
- P% in Waste Sludge = 3.3%

How To Meet 75 µg/l

- Calculate Allowable TSS to Meet P Limits
  - Particulate P = 0.05 mg/l = 0.42 lbs/day
  - P% in Waste Sludge = 3.3%
  - Allowable TSS in Effluent = 0.42/0.033 = 12.7 lbs/day

How To Meet 75 µg/l

- 12.7 lbs/day TSS Effluent
  = 12.7/8.34/1 = 1.52 mg/l TSS

Are We All Scared Yet?

Phosphorus Chemistry

- Influent Phosphorus Typically 4 – 7 mg/l
- Forms are Organic, Polyphosphate, and Orthophosphate
- Biological Treatment Converts most to Orthophosphate and is Soluble
- Orthophosphate Easiest to Remove
- Industrial Discharges may Result in Dissolved Non-Reactive Phosphorus

Phosphorus Removal Chemistry

- Alum (Aluminum Sulfate)
- Ferric Chloride
- Ferric Sulfate
- Lime (Typically Not Used for Municipal Applications)
- Rare Earth Metals (Cerium)

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Phosphorus Removal Chemistry

- Alum (Aluminum Sulfate)
- Combines with Phosphorus to form Aluminum Phosphate
- Minimum Aluminum Phosphate Solubility at pH range of 5.5 to 6.5
- Alum Consumes 0.5 mg/l Alkalinity for Each mg/l of Alum

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Phosphorus Removal Chemistry

- Iron (Ferric Chloride or Ferric Sulfate)
- Combines with Phosphorus to form Iron Phosphate
- Minimum Iron Phosphate Solubility at pH range of 4.5 to 5.0
- Ferric Compounds Consume 0.56 mg/l Alkalinity for Each mg/l of Ferric Chloride or Ferric Sulfate

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Phosphorus Removal Chemistry

- Water Chemistry will be Different at Each Plant
- Jar Testing or Pilot Testing may be Required to Optimize the Chemical and Dosage Required to Reach Low Phosphorus Levels
- pH Should be at 6.5 or lower

Phosphorus Removal Chemistry

- Iron and Alum React with Water to Form Metal Hydroxides
- Complex Chemical Process
  - Metal Phosphate Precipitates
  - Phosphate Adheres to Metal Hydroxides
- More Solids Will be Produced
- Final Clarifier Solids Concentration May Decrease by 20%

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Phosphorus Removal Chemistry

- SorbX-100 Brand Name
- Cerium is Chemical Used
- Precipitate is $CePO_4$
- Forms Ionic Bond
- 1:1 Molar Ratio
- Heavy Precipitate Settles Better Than Fe or Al
- Potential Compliance Without Filtration

Phosphorus Removal Chemistry

- Can Biological Phosphorus Removal Be Used to Achieve Low Level Phosphorus Effluent?
- Typically Not Capable of Getting to 0.02 mg/l Soluble Phosphorus
- Cannot Get 99% Removal

Technology to Meet Low Level Phosphorus

- Maximize Operation?
- Filtration?
- Tertiary Chemical Addition - Filtration
- Tertiary Chemical Addition – Clarification
- Membrane Technology
- Alternative Chemicals
- What Else?

Maximize Operation

- Impact of Influent P Concentration
- Assumptions
  - 0.05 mg/l Particulate P
  - 1,564 lbs Waste Sludge/Day

Inf. P – mg/l	4	5	6	7	8
P - % in Sludge	2.21	2.78	3.34	3.91	4.47
Effluent TSS – mg/l	2.26	1.8	1.50	1.28	1.12

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Maximize Operation

- Vary the Sludge Age (MCRT)
  - Larger MCRT Yields Less Sludge
    - Fixed Amount of P in Waste Sludge
    - Increase in P concentration in Waste Sludge
    - Lower Effluent TSS Required
  - Use Smaller MCRT to Minimize P Concentration in Waste Sludge

Maximize Operation

Impact of MCRT on Effluent TSS

MCRT - Days	Sludge Yield	Sludge – lbs/day	Eff. P – lbs/day	P% in Sludge	Eff TSS – mg/l
10	0.8	1,668	49.4	2.96	1.69
15	0.75	1,564	49.4	3.16	1.58
20	0.7	1,460	49.4	3.38	1.48
25	0.65	1,355	49.4	3.65	1.37
30	0.6	1,251	49.4	3.95	1.27

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Maximize Operation

- Minimize Soluble Phosphorus
- Why?
  - Less Soluble Phosphorus Allows More Particulate Phosphorus and Still Meet Limit
- Higher Chemical Dose
  - Confirm dosage through jar tests or full scale tests
  - Check feed pump size
  - More Sludge

Maximize Operation

- Minimize Soluble Phosphorus
  - Multiple Application Points
    - Add chemical feed pumps for flexibility
  - Add Chemical After Final Clarifier to Minimize Competing Reactions
    - Reduce chemical usage
    - Improve Phosphorus Removal
- Check for Soluble Non-Reactive Phosphorus

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Maximize Operation

- Minimize Soluble Phosphorus
  - Watch pH - < 6.5 Minimizes Soluble P

pH	Solubility of $AlPO_4$ mg/l
5	0.03
6	0.01
7	0.3

Maximize Operation

- Control Phosphorus in Recycle Streams
  - Slug Loads from Recycle Streams can Overload Chemical System
  - Add Chemical Directly to Recycle Stream

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Maximize Operation

- Consider Effluent Phosphorus Analyzers
  - Pace Chemical Feed on Effluent Phosphorus
  - Hach, ASA, Others Make Analyzers

Maximize Operation

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ChemScan® mini oP

Ortho Phosphorus Analyzer

The new single parameter in-line

SPECIFICATIONS

Range (as PO4 - P):	0.03 - 3.0 ppm (Std), 0.1 - 6.0 ppm
Accuracy:	2% of value or 2x detection limit (whichever greater)
Cycle Time:	5 minutes to 9999 minutes (field programmable)
Environment:	5 - 50 degrees C
Power:	100 - 240 VAC, 50 W
Enclosure:	NEMA 4x
Safety Approval:	CSA-US
Sample:	0.5 - 1 Liter/analysis, pressure 5 ft to 10 psi
Maintenance:	Reagent replacement every 3 months, pump kit yearly

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Maximize Operation
Hach Analyzer

Specifications*

	Series 5000 Low Range Phosphate Analyzer	Series 5
Range	0 to 5000 µg/L as PO_4	0.0 to 50.
Accuracy	±4 µg/L or ±4% of reading whichever is greater (typical)	±0.5 mg/ whicheve
Minimum Detection Limit	Less than 4 µg/L	Less thar
Precision	±1% of reading	±0.5 mg/
Step Response Time	15 minutes	11 minut

Operating Conditions
Temperature: 10 to 50°C (50 to 122°F)
Humidity: 5 to 95% noncondensing humidity, suitable for general-purpose, clean, indoor environme

Sample Requirements
Pressure: 5 ±3 psig (34.5 ±20.7 kPa), regulated
Flow Rate: 100 to 300 mL/minute
Temperature: 10 to 50°C (50 to 122°F)

Recorder Outputs
Selectable for 0-10 mV, 0-100 mV, 0-1 V or 4-20 mA

	Output span programmable over any portion of the 0 to 5000 µg/L range	Output s portion o

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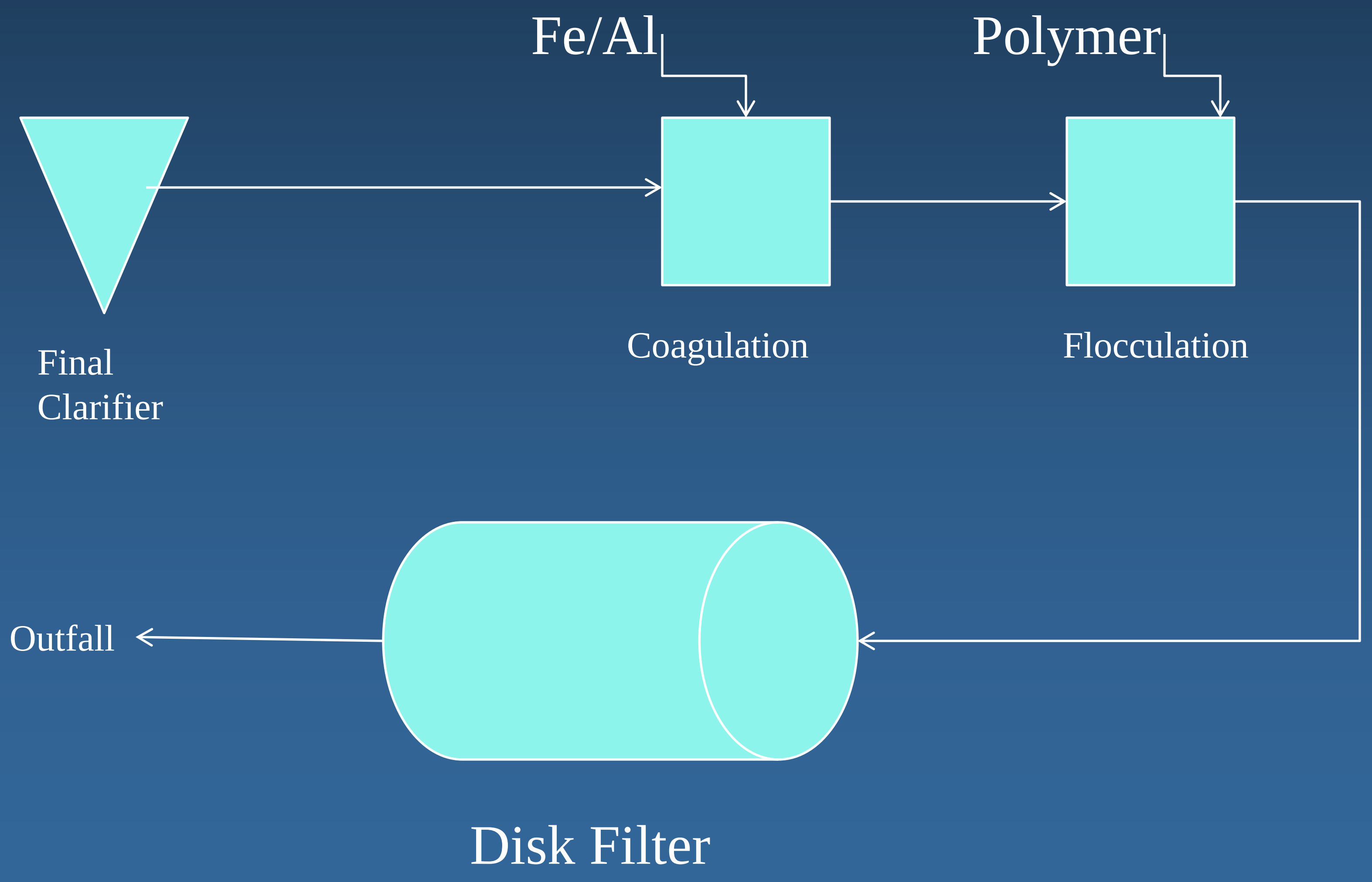
Filtration

- Filtration Alone Unlikely to Meet < 0.1 mg/l Phosphorus
- Need TSS at 1.0 mg/l
- Need Soluble P at 0.02 mg/l
- Too Much Competition for Metal Ions in Activated Sludge to get Ultra-Low Soluble P

Tertiary Chemical Addition - Filtration

- Add More Chemical to Activated Sludge Final Effluent (Metal Salt and Polymer)
- Coagulation and Flocculation Stages
- Disk Filters are Most Cost Effective

Tertiary Chemical Addition - Filtration



Tertiary Chemical Addition - Filtration

- Less Than 0.07 mg/l Can Be Achieved
- Non-Reactive Soluble Phosphorus Has Not Been A Problem Unless Significant Industrial Component of Wastewater

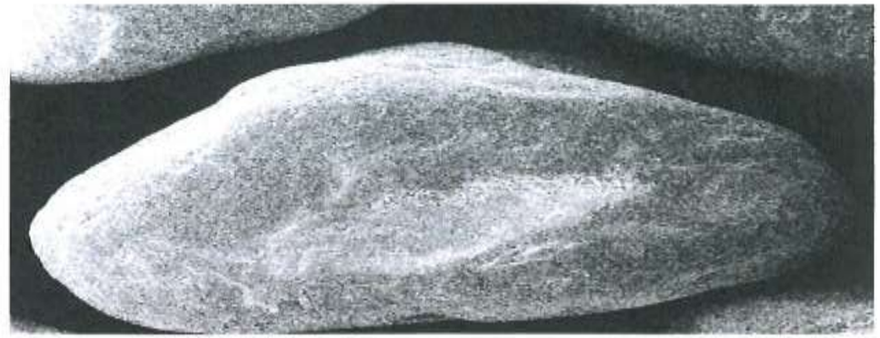
Tertiary Chemical Addition/Two Stage Filtration

- Add More Chemical to Activated Sludge Final Effluent
- Operate Granular Media Filters in Series
- DynaSand D2
- BluePRO
- Above are Proprietary Processes
- Capable of 0.02 mg/l P in Effluent

HYDROUS FERRIC OXIDE (HFO) COATED SAND

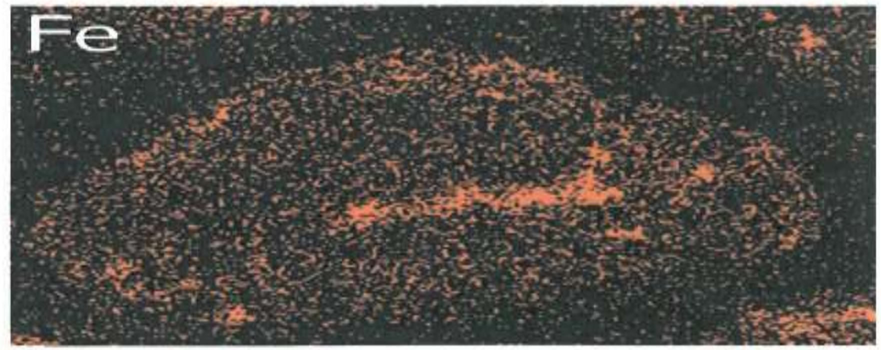
Adsorptive Media - Technical Summary

The Blue PRO® process is distinguished from other wastewater treatment processes by its mechanism of removal. Blue PRO® optimizes adsorption of contaminants, rather than relying on coagulation-filtration. Adsorption within the filters lowers contaminants to extremely low concentrations by overcoming equilibrium and diffusion limitations. The picture to the right is a scanning electron microscope (SEM) image of sand taken from deep inside a Blue PRO® filter.



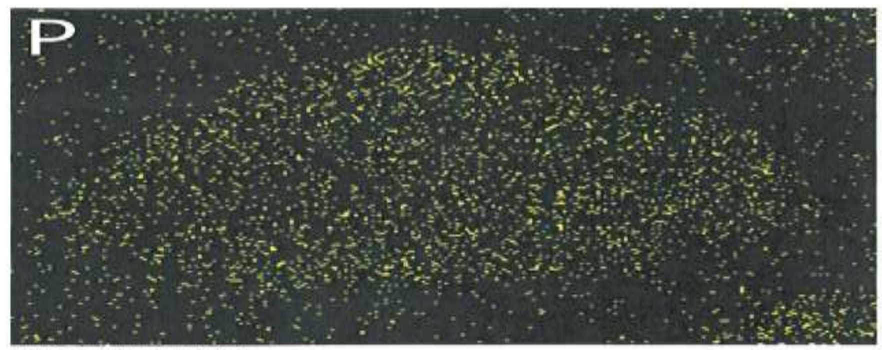
SAND GRAIN

Continuous, fresh regeneration of the HFO coating on the surface of the sand grains is a patented process applied to the Centra-flo™ moving bed filter. This process creates unusually high adsorptive capacity, even greater than aged iron oxide-coated sand (IOCS) media. This X-ray fluorescence (XRF) image of the same sand grain shows iron on the sand, ready to adsorb contaminants under a wide range of pH values and contaminant concentrations.



IRON COATING

This second XRF image shows phosphorus that is coordinated with the iron on the sand grain. After adsorption within the filter bed, the iron and phosphorus are subsequently abraded off the sand and passed out of the filter with the waste particulates. The sand is retained within the filter. The waste stream may be recycled within a wastewater plant for additional benefits from reactive capactiy, may be added to the existing sludge handling system, or easily dewatered for separate handling.



PHOSPHORUS

*Images courtesy of the University of Idaho

Blue PRO®

BluePRO® Reactive Filtration Series System

The BluePRO® process schematic is shown in Figure 3. An iron-based chemical was added to the wastewater before it passes into the rapid conditioning zone, which allows the proper contact time for the mixture to optimize the adsorption process. The mixture enters the moving bed sand filter through distribution arms at the bottom of the sand bed, flowing upwards through the sand bed. The BluePRO® process uses ferric chloride or ferric sulfate for continuous regeneration of the hydrous ferric oxide-coated media for adsorption of phosphorus. After filtration, treated water discharges from the top of the filter. Internally, the sand moves slowly from top to bottom, then is returned to the top of the filter by an airlift located in the central assembly. After adsorption, the iron and phosphorus are abraded off the sand both in the sand bed and in the airlift. A washbox at the top of the filter separates sand from iron and phosphorus waste particulates. The sand is retained within the filter and falls back to the top of the bed; the residuals, including the iron and phosphorus or other contaminants, exit in a reject line.

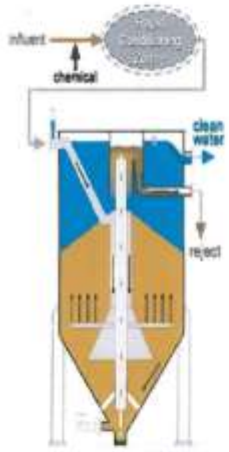


Figure 3 – Schematic of BluePRO® Reactive Filtration (Courtesy of Blue Water Technologies)

Membrane Technology

- Membrane BioReactor (MBR)
  - Activated Sludge Process that Substitutes Final Clarifiers with Low-Pressure Membranes
  - Ultrafiltration Class Membrane Yields TSS <1.0 mg/l
  - High Chemical Use to Get All Phosphorus in Particulate Form

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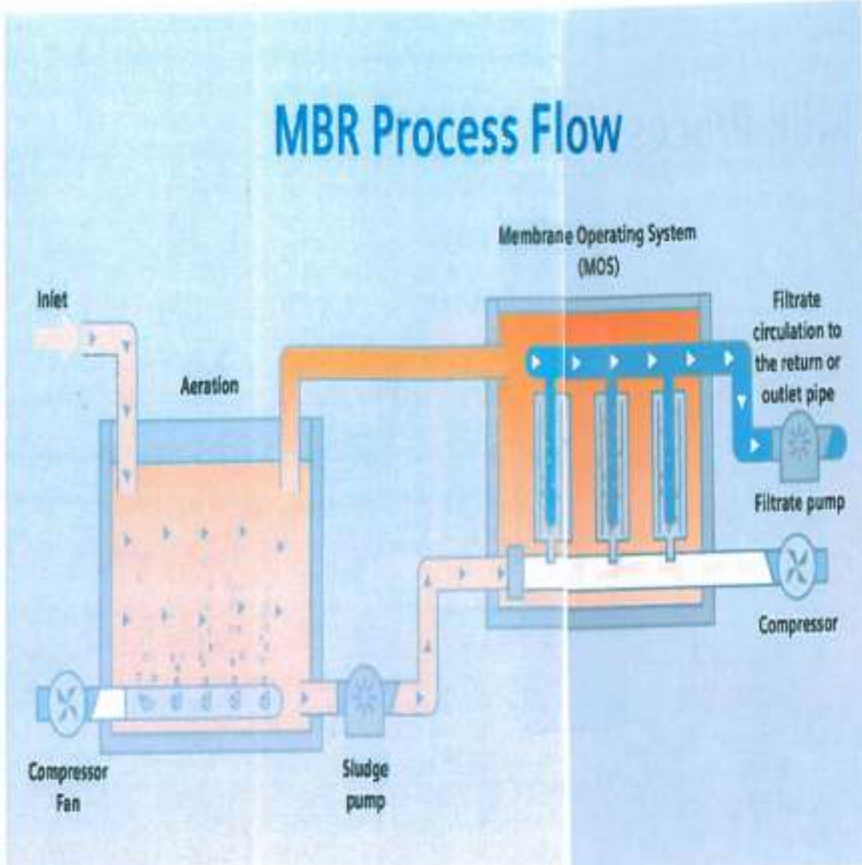
Membrane bioreactor – innovative technology for clean water

Optimize your water resources – with the Siemens membrane bioreactor. The Siemens membrane bioreactor allows you to effectively purify wastewater with very low impact on the environment. Minimize your production costs by treating wastewater and reusing it – using the very latest membrane technology.



Membrane Technology

- Tertiary Membrane
  - Membrane Used as Tertiary Filtration
  - If Soluble P is low, Capable of Low Effluent P and TSS < 1.0 mg/l.

Tertiary Chemical Clarification

- Add More Chemical to Final Clarifier Effluent in Rapid Mix/Coagulation Step
- Flocculation Step with Polymer Feed
- Clarification (Lamella Type) with Ballasted Settling
- Add Filtration for Ultra-Low P Effluent

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Tertiary Chemical Clarification

- Ballasted Flocculation
  - Actiflo Uses Sand
  - Co-Mag Uses Magnetite
- Add Chemical for P Removal that Forms Flocs Around Sand or Magnetite
- Ballast Recovery Process
- Rapid and Efficient Particle Settling

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Veolia ACTIFLO® Process Followed By Gravity Filters

ACTIFLO® is a compact process that operates with microsand (Actisand) as seed for floc formation. The microsand ballasted flocs have enhanced settling characteristics, which allow clarifier designs with very high overflow rates and short retention times. The ACTIFLO® process comprises coagulation, sand and polymer injection, floc maturation, lamella clarification, and sand recovery, as shown in Figure 5.

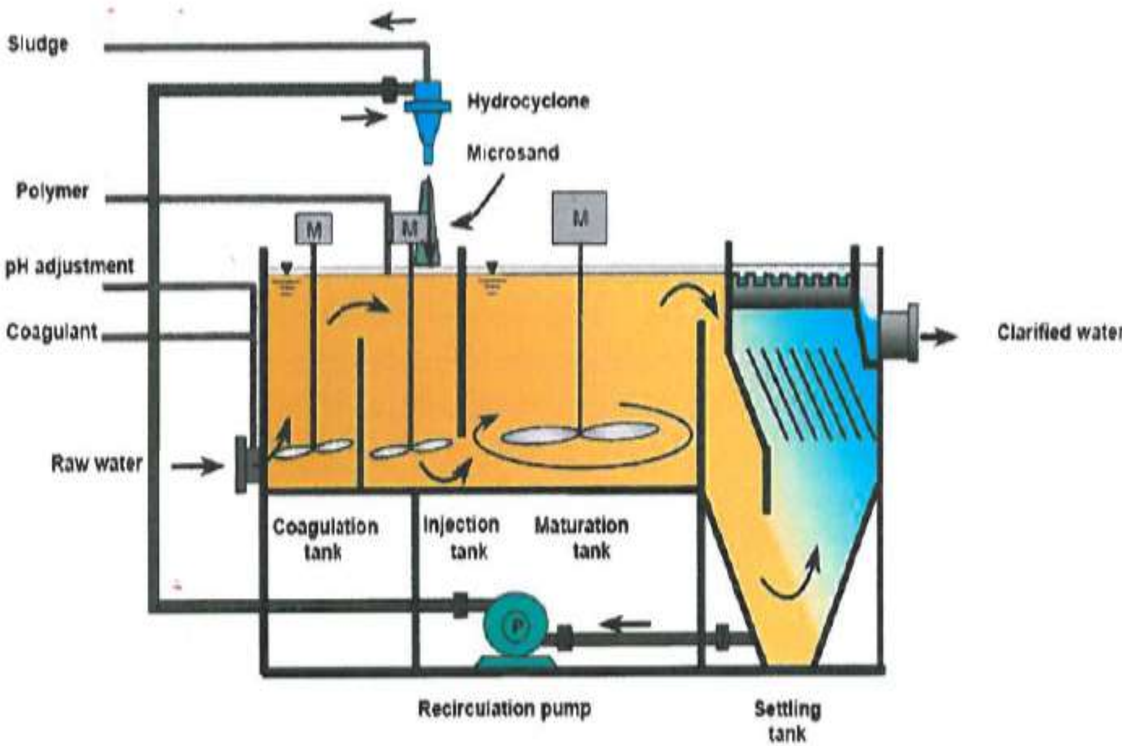
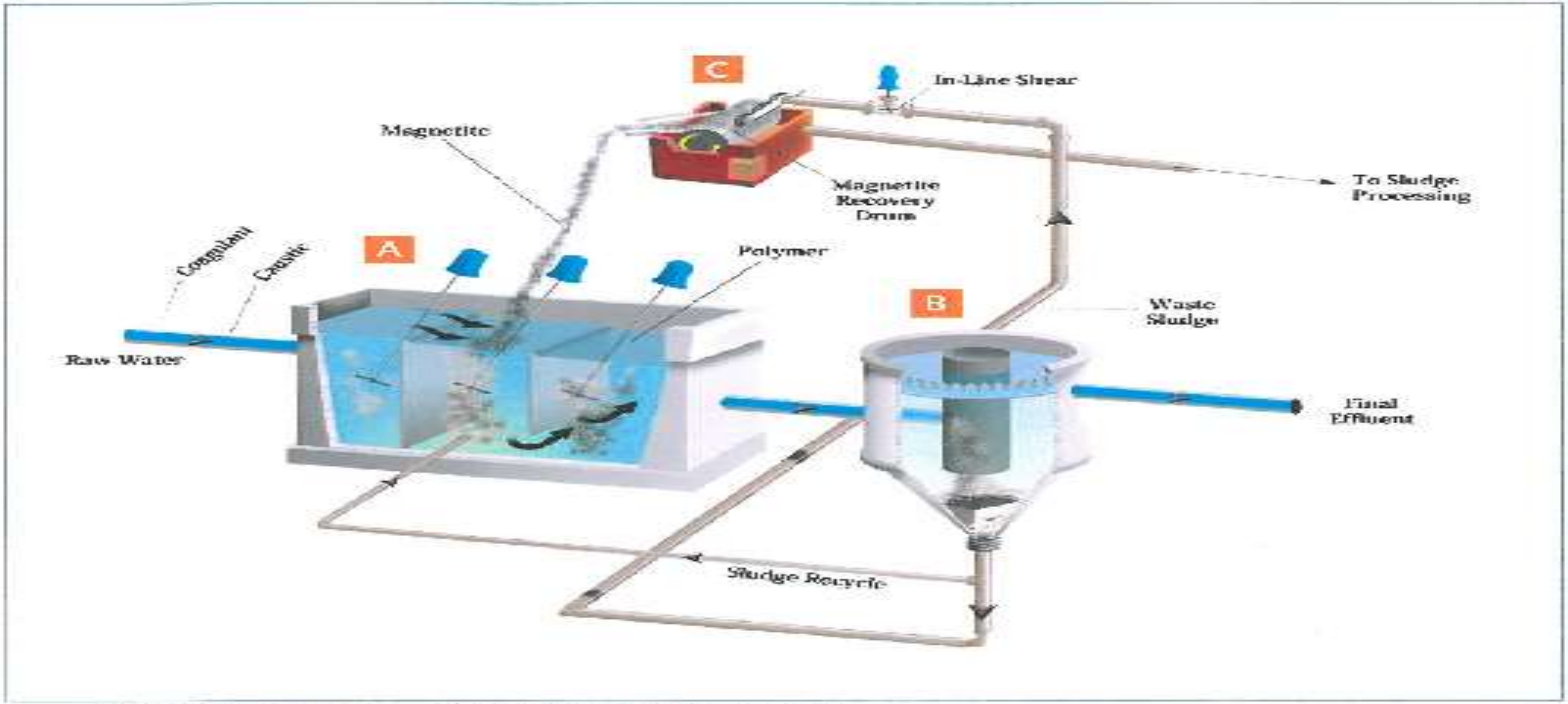


Figure 5 – Schematic of ACTIFLO® Process (Courtesy of Veolia)



The CoMag™ system as part of a traditional tertiary treatment configuration

What Else May Prove Effective?

- Adsorption
  - Activated Aluminum Oxide
  - Granulated Ferric Hydroxide
- Potential to Remove Difficult Soluble Phosphorus Compounds

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Summary

- Low Level P Removal Requires
  - Near zero soluble P
  - 1-2 mg/l TSS to removal particulate P
- High Level of Chemical Required
- High Level of TSS Removal Required

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Summary

- Technologies for Low Level P Removal
  - Filtration with Chemical Feed
  - Tertiary Membrane
  - Membrane Bio-Reactor
  - Tertiary Chemical Treatment/Ballasted Flocculation
  - Adsorption

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