Final Clarifiers – The Achilles’ Heel Of Phosphorus Compliance

Samuel Jeyanayagam, PhD, PE, BCEE

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Who is Achilles?

Achilles is the central figure & the greatest warrior in Greek mythology, Homer’s *Iliad*.

He was said to be invulnerable in ‘all of his body’ except his heel, which was a point of weakness.

Achilles’ Heel: A deadly weakness in spite of overall strength, which can potentially lead to downfall.
Presentation Outline

- Background
- Functions of a Clarifier
- Tools for Clarifier Analysis
- Take Home Messages
Phosphorus Speciation

Removed by EBPR or Chem-P removal
Non Reactive P
Determined by solids capture efficiency (clarifier & filter)

Determined by solids capture efficiency (clarifier & filter)

Soluble Reactive P
Soluble
Particulate
Particulate P
Effluent TP
Impact of Effluent TSS

Effluent Particulate Phosphorus, mg/L

75% VSS

EBPR Solids

Secondary Solids

Effluent TSS, mg/L

- 12% P
- 8% P
- 6% P
- 2% P

0.12 mg-P/mg-VSS
0.08 mg-P/mg-VSS
0.06 mg-P/mg-VSS
0.02 mg-P/mg-VSS
Clarifier is a Crucial Component of the Treatment Train

- It often limits the capacity of the entire facility
- Plays a central role in controlling effluent phosphorus
- In many plants it is the last opportunity to clean-up the effluent prior to disinfection
- Care should be taken in its design & operation
Clarifier Analysis should be based on a **Systems** Approach

Settleability

Aeration Basin

MLSS

RAS

SRT

SLR

WAS

Effl. TSS

Clarifier Performance

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Functions of a Secondary Clarifier

1. Clarification:
   - Solids separation
   - Involves a small fraction of the solids inventory

2. Thickening
   - Transport & compaction
   - Involves a majority of the solids inventory

3. Storage
   - Clarifier acts as a wide spot during peak loadings

A clarifier must be able to perform **all** three functions.
Clarification Function

- Clarification involves two velocities
  - Downward velocity of solids
    - Solids settling velocity \( (V_s) \)
  - Upward velocity of water
    - Rise velocity = Overflow rate (OFR) = \( Q/A \)

- If OFR > \( V_s \)
  - Solids carryover
  - This is clarification failure
Thickening Function

- Every clarifier has a limiting flux: Maximum rate at which solids can be conveyed to the bottom of the clarifier.

- If Solids in > Limiting flux
  - Solids accumulate in clarifier
  - Rising sludge blanket
  - This is thickening failure

- If this continues, sludge will reach the effluent weir:
  - Solids carryover
In Summary

- Clarification Failure
  - Thickening Failure
  - Sludge Blanket Increase

- High Effluent Solids

- Non-Compliance
  - Total P
  - Ammonia-N
  - TSS
Common design approach is based on empirical equations
- Solids loading rate
- Overflow rate
- Weir loading rate

These design criteria are:
- Good initial checks
- But not linked to sludge quality
Presentation Outline

- Background
- Functions of a Clarifier
- Tools for Clarifier Analysis
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Tools for Analyzing/Predicting Clarifier Performance

- State Point Analysis
- Daigger-Roper Operating diagram
- Keinath operating charts
- Ekama-Marais approach
- Wilson approach
- Computational fluid dynamic modeling
Terminology

- **Overflow rate (OFR)**
  \[
  OFR = \frac{Q}{A}
  \]

- **Underflow rate (UFR)**
  \[
  UFR = \frac{Q_{RAS}}{A}
  \]

- **Solids loading rate (SLR)**
  \[
  SLR = \frac{(Q + Q_{ras}) \times X \times 8.34}{A}
  \]

- **Flux**: Movement of solids (mass) through the clarifier
State Point Analysis

- Extension of the solids flux theory
- Entails 3 elements
  - Settling flux curve
  - Overflow rate line
  - Underflow rate line

Allows the behavior of the clarifier to be examined in conjunction with the activated sludge process
State Point Analysis Starts with Simple Settling Tests
Settling Velocity

Settling Curve for a given MLSS (X)

Settling Velocity ($V_s$) = Slope of Linear Portion
Solids Flux Curve

Solids Flux (G), $\text{kg/m}^2 \cdot \text{h}$

$$G = V_s X$$

This gives one point on the flux curve. Repeat test at different solids concentrations to get multiple points.

Good settleability = Greater area under the curve relative to poor settleability.
State Point Analysis (SPA)

Superimpose Clarifier Operating Parameters
- Overflow rate (OFR = Q/A)
- Underflow rate (UFR = Q_{ras}/A)
Rate = Slope

Clarification Failure: Location of the State Point

Thickening Failure: Location of UFR.
Application of SPA

- When clarification or thickening failure occurs:
  - Operator intervenes to correct the situation
  - If this doesn’t happen the clarifier responds by self-correcting itself, but this may impact the biological process
- SPA can be used to explain these two eventualities
Application of SPA Diurnal Flow Variation

Small flow increase due to normal diurnal variation
- Stable operation
- Reduced safety factor
- No action by operator
Large flow increase due to wet weather

Clarifier response:
- Solids washout
- Reduced MLSS & SRT
- Nitrification loss

Operator response:
- Convert to step-feed; reduce MLSS conc. to clarifier
- SRT not impacted - Nitrification maintained
Good settleability (low SVI)
Stable operation

Poor settleability (High SVI)
Clarifier response
- Solids washout
- Lower MLSS
- Nitrification loss

Operator response
- SRT control
- RAS chlorination
- Polymer addition
Daigger-Roper Operating Chart is Also Based on the Solids Flux Theory

[Diagram showing the relationship between RAS Concentrations, mg/L, and Allowable SLR, lb/d/ft², with isoclines for Underflow (RAS) Rate (gpd/ft²) and SVI (mL/g).]

Increasing Underflow Rate

Increasing SVI
Daigger-Roper Operating Chart

<table>
<thead>
<tr>
<th>Operating Point</th>
<th>Operating SLR</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Left of Current SVI</td>
<td>&lt; Allowable SLR</td>
<td>Stable</td>
</tr>
<tr>
<td>B. On the Current SVI</td>
<td>= Allowable SLR</td>
<td>Crucially loaded; failure imminent</td>
</tr>
<tr>
<td>C. Right of the Current SVI</td>
<td>&gt; Allowable SLR</td>
<td>Overloaded</td>
</tr>
</tbody>
</table>

Locate operating point using two of the following:
- Clarifier solids loading rate (SLR)
- Underflow (RAS) rate
- RAS solids concentration
Poor Settleability (High SVI) Means Small Safe Operating Region
Limitations of Solids Flux – Based Tools

- One dimensional visualization of flow (vertical). In reality flow is 3 dimensional.
- Doesn’t account for hydraulic inefficiencies & short circuiting.
- Assumes good bio-flocculation, deep clarifiers, and no density currents – ideal clarifier.
- Can not predict effluent TSS. Prediction limited to 3 conditions - stable, critically loaded, or overloaded.
- SVI is an imperfect representation of settleability. But at this time, it is the most readily usable parameter.

These concerns are addressed by applying a 5 – 20% derating factor based on clarifier depth, extent of flocculation, and hydraulic inefficiency.
The Value of Computational Fluid Dynamics (CFD) Modeling

CFD modeling is the **only** tool that allows us to:

- Examine all of the factors that influence clarifier performance:
  - Flow
  - Mixed liquor concentration
  - Temperature
  - Internal features of the clarifiers
  - Sludge volume index, extent of bioflocculation

- Ask ‘what if’ questions – cost vs. benefit:
  - Baffles, energy dissipating inlets, sludge withdrawal, etc.
CFD Modeling Can Unlock Final Clarifier Bottlenecks
Enhancing Sludge Settleability

- Many options available – discussed in several publications
- Mixed liquor degassing
- Phage therapy
Thinking Outside the Box
Mixed Liquor Degassing!

Floc with entrapped gas bubbles

Specific Gravity ~ 1.0
Light and fluffy; poor settleability

Degassed Floc

Specific Gravity ~ 1.1
Compact and heavier; enhanced settleability

Courtesy: Matt Maciejewski
Phage Therapy

- Phages are viruses that infect bacteria (filaments)
- They are bacteria-specific
  - Coliphage infect coliforms
Presentation Outline

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- Functions of a Clarifier
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Take Home Messages

- Final clarifiers often determine the capacity of the entire facility.
- Textbook design criteria are good initial checks but are not linked to sludge settleability.
- State Point Analysis allows the behavior of the clarifier to be examined in conjunction with the activated sludge process.
- Clarifiers are NOT miracle workers. Even a well designed & perfectly operated clarifier is limited in its performance by sludge settleability.
- Any strategy for enhancing clarifier performance should first consider improving sludge settleability.
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Samuel.Jeyanayagam@CH2M.com

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