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OPTIMIZING CLARIFIER DESIGN and PERFORMANCE

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INTRODUCTION:

The most important point to remember when evaluating any wastewater treatment facility whether small, medium or large is that it's performance is impacted by a combination of factors. These factors have been nicely categorized by Bob Hegg in his EPA manual "Retrofitting POTW's" into the areas of operations, maintenance, design and administration. So, when evaluating and looking for opportunities to improve clarifier performance, remember to investigate each of these functional areas for factors that may be limiting its performance.

How can you then tell what's best for your clarifier? The answer is that often you can't tell without trying it out first at your plant. We've seen too many theories and mathematical models presented and so-called nifty modifications marketed that simply don't work in many wastewater plants. There are often small differences and sometimes major differences between clarifiers that appear to look alike. This is a lesson to remember. Because of these differences, we have to learn to apply some caution when dealing with clarifiers. We suggest first trying to find out what makes your particular clarifier "tick"; this is the real challenge in the optimizing process.

The following outline is a summary of ideas that are intended to help you avoid some of the problems that have been identified in clarifiers, and to point you in the right direction for change. Most of what I've written comes directly from our field experience, but a lot of valuable observations are from the shared experiences of others. I think you'll be able to find something useful here that will make your life at the plant a bit easier.

I. REMEMBER THAT THE CLARIFIER IS A PART OF A SYSTEM

- A. Preliminary Treatment: effects rag, grit and grease removal; incredibly important when suction clarifiers are involved!!
- B. Equalization: what every operator dreams of having; should be sized for production excesses and storm water.
- C. Raw Sewage Pumping: should always be variable speed.
- D. Cooling systems and backwash water are major contributors, esp. for paper industry
- E. Primary Clarifiers: where you can really protect the downstream units.

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- F. Aeration Units
1. Surface Mechanical aerators:
 - May have an adverse impact on floc formation but it can be remedied.
 - Effect on heat transfer? Definitely, esp. in northern climates.
 - Effect on Nocardia and M. Parvicella scum production? You bet!!!
 2. Scum passing over from aeration will increase the MLSS and decrease settleability.
- G. Flow Distribution to clarifiers dramatically affects performance !!
1. Plan for future expansion without compromising the present.
 2. The lack of hydraulic balance generally leads to poor distribution.
 3. Design to be able to control flows during the "operational imbalance" caused by taking a clarifier out of service.
 4. Automated flow-balancing systems work best when paced by open- channel effluent flow meters for each clarifier.
 5. An upflow, overflow distribution box of adequate size with adjustable overflow weirs works best.
 6. **Always** provide a flow measurement device for **each** clarifier!
- H. Stormwater and Stormwater Storage Flows
1. Provide for bypass or storage to protect the biological process.
 2. If no bypass ??
 - a) Go to step-feed or contact stabilization mode.
 - b) Reduce or turn off aeration (i.e. mixing) to retain solids in aeration.
 - c) Try forcing excess flow to just one aeration basin, that way you don't have to report it as bypassing☺
 - d) Use an aeration basin for storage of RAS flow.
 - e) Be aware of the temperature effects of the colder stormwater on the biological system and its settling characteristics.
- I. Return Sludge Flows
1. Provide lots of pump capacity as well as good turn-down capability.
 2. Avoid RAS pump headers or wet wells that serve multiple clarifiers.
 3. Always provide separate RAS pumps for each clarifier with individual flow meters that work!

II. IS SHAPE A FACTOR IN PERFORMANCE ?

- A. "Yes" and "No"; rectangular and circular clarifiers each have their advantages and disadvantages due to their shapes.
- B. **However**..... the **best-performing** clarifier we've seen as tested by the ASCE-CRTC protocol, and proven by time!..... is rectangular 150' long by 20' wide and only 9.5' deep! and with **co**-current sludge removal! (L.A. County San. Dist. – San Jose Creek).
- C. **Another** good rectangular clarifier (@WSSC) is 12-ft deep at the influent and only 6-ft deep at the effluent end!!! It finally "failed" at **70 lb of solids per square foot!!!!**
- D. The **poorest** shape is always the "squircle" (square) followed closely by the "double squircle" and, yes, the "triple squircle" (Cleveland; Cincinnati; Passaic Valley)! But even they can be improved!! (esp. ask me how to improve a standard squircle!!)

III. IS DEPTH A FACTOR ?

In unmodified clarifiers, extra depth has some beneficial effect, primarily for additional sludge storage during diurnal variations and thickening overload. It also may be slightly effective in reducing the solids loss from the upwelling of the density current at the wall but is it really cost-effective in your situation?

Remember, the **best** clarifier that we've ever seen (ref. II B) has only a **9.5-foot SWD!** So don't be fooled by rating curves that try to relate performance solely to depth.

IV. INTERNAL DETAILS HAVE A GREAT EFFECT ON PERFORMANCE

- A. Influent flow balance: must provide a means to measure flow!!
- B. Inlet Design:
1. Avoid scouring (turmoil!) in the central area of the clarifier.
 2. Provide for flocculation: see L.A. City/County inlet nozzle design for rectangular clarifiers; consider an energy-dissipating inlet for circular clarifiers. (see the L.A. City-Hyperion plant design / "LA-EDI")
 3. Distribute flow horizontally? Yes; see L.A. City/County nozzle design for rect clar.
 4. Distribute flow vertically ?
 - Only necessary in primaries or in secondaries following fixed-film reactors.
 - Tangential port EDIs can cause **excessive blanket scour and solids loss**.
 - Be wary of the "waterfall" effect from EDIs with a near-the-surface discharge.
- C. Sludge Withdrawal Mechanisms in Circular Clarifiers:
1. RAS draft tubes should be aligned horizontally, not vertically and sized properly!. Beware of short-circuiting from inlets.
 2. Manifold-type suction mechanisms have a full floor suction pattern if the orifices aren't plugged!! Or, if the manifold isn't full of sludge!
 3. Slow the collectors down?? Definitely should in "squirrels".
 4. Speed them up? beware of disturbing the sludge blanket.
 5. The draft tubes feeding the RAS sight box will interfere with the influent ports, leading to very uneven flow distribution.
- D. Hydraulic Sludge Withdrawal (RAS) Tube Flow Control:
- 1 Submerged gates are difficult to control individually.
 - 2 Telescopic valves theoretically provide better control, but they are difficult to adjust and usually collect rags. Avoid them.
 - 3 Use "twist-turn" control tubes for easier control and maintenance.
 - 4 Avoid plugging problems by reducing the number of tubes in service.
- E. Sludge Scrapers:
1. Standard segmented plows work well, maybe better than spiral scrapers (and may even be better than draft-tube suction-type?).
 2. Consider adding some extra depth to standard scraper collectors.
 3. Spiral scrapers? A more expensive retrofit which are **not** an "improvement" over standard scrapers! not a "silver bullet"!!

4. Spiral scrapers alone didn't improve performance at Manchester, or L.A., or Phoenix, or Boca Raton but did cost a lot of money!!!
 5. Spiral scrapers caused very poor performance in primaries (FL, RI, and DC?)
 6. Remember, sludge **flows downhill** if you provide a 1"/ft floor slope.
 7. Scraper Tip speed? Definitely no need for VFDs; stay with 10-12 fpm.
- F. Circular Centerwells:
1. Problems with scum? Design relief ports for it; use a skimmer blade?
 2. Optimum depth? Less than 0.5 x SWD; avoid DEEP centerwells.
 3. Optimum diameter? Who knows?? Maybe 0.2 D+/-; avoid LARGE centerwells.
 4. Designing to enhance flocculation? Beware of problems with the standard tangential port energy-dissipating inlet. (A much better proven device is the "L.A.-Hyperion inlet").
 5. Avoid using a return shelf ("lip") on the bottom of the centerwell.
 6. Do **NOT, i.e. NEVER, EVER** keep the top rim below the water surface.
 7. Provide flocculators? They are effective in some chemical plants, esp. when using polymers, but generally not useful in POTW's.
- G. Scum Collection w/ Circular Clarifiers:
1. Avoid a perpendicular alignment of the skimmers; use tangential alignment.
 2. Use large scum hopper and drain pipe (8" min.).
 3. Multiple scum hoppers are an unnecessary option.
 4. Provide underwater flushing port for hoppers.
 5. **Best idea:** Install a simple "anti-rotation scum baffle" (such as the "Scum Bum").
 6. Plan for getting lots of scum like Nocardia and M. Parvicella !!
 7. Always provide for safe access to scum hoppers.
 8. Ducking skimmers? NG! Cost lots of \$\$\$ return lots of water and preclude ever having the very useful option of providing an algae sweep mechanism.
 9. Full-radius scum beach? Maybe (just maybe) OK on smaller clarifiers, not on larger.
- H. Rectangular Sludge Collection (w/ scrapers):
1. MUST provide for scum removal !!!
 2. Scraper speed? Normal rate is 1-2 fpm; 4+ fpm has worked OK.
 3. How slow can they go? 1 fpm OK w/ fixed film; OK w/A.S. too.
 4. What kind of chain? Non-metallic! It's easiest and long-lasting!!
 5. Provide a bottom slope for max solids handling?? 1/2" per foot??
 5. Travelling Bridges? They really complicate the collection process, and force the currents and flow to launders at the far end, and are usually maintenance nightmares! 'Nuff said??
- I. Inlets for Rectangular Clarifiers:
1. L.A. City/County opposing jet nozzle design is best.
 2. Submerged gates w/ head differential are good, but plan for lots of scum removal from the distribution channel.
 3. Deep inlet baffles are NG; they increase the density current effect.
 4. Overflow inlet weirs increase the density current and nocardia foam generation; they also foul too easily.

- J. Location of RAS Hoppers in Rectangular Clarifiers:
1. At inlet end is the standard condition. It's OK, but be prepared to deal with the typical deleterious density current.
 2. At middle (Gould type II) is best in long (200'+/-) clarifiers; will have a useful density current in first half and variable currents in second half! (but it would still help it to have interior baffles!)
 3. RAS hopper at effluent end ?? This configuration works great at all L.A. County plants! This is the probably the best hopper location.

V. WEIR PLACEMENT IS CRITICAL!!

- A. In standard Rectangular Clarifiers (w/o baffles):
1. Worst Conditions:
 - a) at or near the end wall, or close together
 - b) with interior launders deeper than necessary.
 - c) with **short** (finger) weirs perpendicular to end wall.
 2. Better Conditions:
 - a) covering at least 20% of surface.
 3. Best Conditions:
 - a) covering at least 30% of surface.
 - b) having the ability to measure the flow.
 - c) w/ adjustable weirs that are able to be taken out of service.
 - d) no deeper than necessary !!
 - e) esp., have two launders parallel to the flow (see L.A. County/City)
- B. In Circular Clarifiers (w/o baffles):
1. Worst Conditions:
 - a) with a single perimeter weir that's flush w/ face of wall, or even attached to the launder inside the face of the wall.
 - b) a cantilevered launder that's deeper than necessary.
 - c) a cantilevered launder that's too close to the wall.
 - d) a single perimeter weir with a close inboard launder.
 - e) located at the perimeter in conjunction with a perimeter influent channel.
 2. Better Conditions:
 - a) A launder cantilevered about 0.20R inboard
 - b) that's not too deep!
 - c) Spiral flow peripheral feed w/ central launder (for lower OFR's).
 3. Best Conditions:
 - a) a "reasonably sized" (say, 0.2 diam) centerwell w/ launders cantilevered 25% diameter inboard
 - b) and with the new "L.A.-EDI" flocculating / energy-dissipating inlet

VI. THE EFFECT OF MAINTENANCE ON PERFORMANCE

- Periodic Maintenance: should **dewater and inspect at least once/yr!**
- Torque Overload Protection should be checked frequently.
- Rotating top **and bottom** seals (on suction manifolds) must be checked; must dewater the clarifier in order to inspect properly.
- The RAS sight well center column seal needs periodic replacement.
- Inlet ports on peripheral feed clarifiers must be unplugged periodically.
- Weir leveling is very important; shd be done right ONCE at start-up.
- Algae growth can actually shut off flow over portions of the weir. Plan for periodic cleaning or else!
- For effective algae control consider that:
 1. a hypochlorite solution piping under water near the scum baffle or weir works well.
 2. the automatic brushing systems are also slick! (AKA the "Weir Wolf")

For safety's sake, provide

1. safety screens/bars at the outlet/drop chute of the effluent launders.
2. safe access to the launders and the scum hopper.
3. for easy access for maintenance of gear drives.

VII. THE EFFECT OF OPERATIONS ON PERFORMANCE

- A. Sludge Blanket Level Control: a critical activity.
 - Keeping blankets low is the best way to accommodate high flows.
 - A slightly higher blanket may optimize nitrate reduction for BNR
 - Increase the blanket monitoring activity during high flows.
 - Manual core samplers (Sludge Judge) are useful, but very subjective.
 - Some electronic blanket detectors are very reliable and useful.
 - Hand-held electronic blanket detectors are very useful; they provide for uniform measurements by staff, even w/ typically poor lighting conditions at the clarifiers.
- B. SVI Control:
 - This is (maybe?) the most important process control activity (How LOW can U go?)
 - Every operator should know how to identify and control filaments. (or at least have access to someone who does!).
 - Larger plants should have a good phase-contrast microscope.
 - Seek the lowest SVI that you can develop as an operating standard.
- C. MLSS Control:
 - It's your call on what's the proper concentration; i.e. use whatever works best for your process and sludge dewatering system.
 - Generally, operating with the lowest MLSS is better (i.e. leads to a lower solids loading)
- D. Nutrient Control: be aware of your minimum N and P requirements.
- E. Be diligent about scum removal, esp. to control odors and to reduce freezing problems; fabricate and install your own "anti-rotation" scum baffle.
- F. Beware of M. Parvicella scum mixing w/ MLSS and RAISING SVI!!

- G. Flow Balancing:
- You **must** be able to measure and control the flow to (or from) each clarifier; that means installing simple flow measurement weirs, etc.
 - You **must** be able to measure and control RAS from each clarifier.
- H. RAS Control:
- RAS rate can effect hydraulic performance, esp. in circular centerfeed clarifiers.
 - The RAS rate effects treatment time in aeration reactors.
 - RAS tube selection: you should control or take tubes out of service in order to optimize RAS concentration and blanket level control.
 - Flush RAS tubes automatically every night.
 - "Solids Flux / State Point" concept: can be useful in predicting the typical clarifier blanket thickening failure, or for examining "what if?" situations.
 - Remember the basic concept that "pounds out" (as RAS) must balance the "pounds in" (as MLSS).
 - The diurnal fluctuation of blanket levels often yields a helpful diurnal change (increase) in the RAS concentrations. But it can also lead to diurnal solids washouts!
- I. Effluent TSS monitoring
- Monitor the ETSS periodically from each clarifier for best process control.
 - Compare clarifier ETSS with settleometer supernate TSS for better clarifier process control.
 - Use DSS and FSS tests for diagnostic observations.
 - Occasionally, check the diurnal ETSS pattern.
 - Use a low-level TSS meter or turbidimeter for on-line control.

VIII. USE OF POLYMERS (especially important for industrial plants)

- Consider CEPT (chemically enhanced primary treatment) to reduce organic loadings (and energy costs!) on secondary systems.
- Consider polymer use (CEST?) to enhance flocculation for improving settling rate, reducing sludge blanket thickness, and reducing ETSS.
- Consider certain polymer use for the control of certain types of filaments, i.e. M Parvicella.
- Polymers may be a cost-effective temporary solution (esp. during wet weather events), and even a cost-effective long-term solution (i.e. instead of adding more clarifiers).
- Laboratory jar testing should mimic the actual plant conditions with respect to mixing time and mixing intensity.
- Always use the "stirred" settlometer test for determining SSV's for SVI when using polymers for treatment.
- Provide for multiple feed points, effective initial mixing and distribution.
- Be wary of the effect of a more compact blanket on collector torque.
- Be wary of too much polymer >>>> flotation problems, "whale" problems.
- Periodically confirm chemical doses with DSS and FSS testing.

IX. STEPS IN ANALYZING CLARIFIER PERFORMANCE

First

- A. Determine and equalize the flow distribution to each individual clarifier.
- B. Determine and equalize the individual clarifier return sludge flows; confirm RAS flow meter accuracy.
- C. Monitor the biological or chemical treatment performance with respect to flocculation (use microscope; jar tests; settleometer).
- D. Determine individual clarifier ETSS performance at various overflow rates and blanket conditions.
- E. Monitor changes in blanket profiles at selected locations; monitor the diurnal blanket changes. (do Vertical Solids Profiles/VSP's)
- F. Monitor effluent turbidity during stress tests.
- G. Look for diurnal ETSS variations (esp. the time of the peak blanket levels and ETSS).
- H. Optimize the activated sludge quality for your plant conditions.

Then Determine the Actual Clarifier Hydraulic Characteristics.

1. With dye testing, determine the actual detention times.
2. Observe overall flow patterns at different locations and during different conditions.
3. Measure currents using drogues, looking for reverse currents and unusual currents.
4. Examine the currents at different depths and locations.
5. Determine the full depth vertical solids profiles (VSP's) multiple times during testing.
6. Determine the effects of the individual launders and weirs with dye and grab TSS samples
7. Determine the location and intensity of short-circuiting currents.
8. Look for temperature effects following fixed-film reactors or with warm industrial wastes (esp. in primary clarifiers), or with steel tanks.
9. Determine the impact of higher and lower RAS rates.

X. IMPROVING INTERNAL CLARIFIER HYDRAULICS

- A. This activity is **by far** the most cost-effective means of improving clarifier performance and increasing plant capacity!!
- B. Refer to the work of Bob Crosby in improving circular clarifiers, especially:
 1. the 45° Crosby sloped-peripheral baffle @ Stamford, CT, improved average ETSS by > 30%. NOTE: It does not reduce short-circuiting; it does increase density currents; we recommend a 45° slope for most situations! (seldom a 30° slope!)
 2. the Crosby mid-radius/cylindrical baffle: CPE projects @ Franklin, (NH), improved ETSS by >35%; worked well at Atlanta (GA), NYC, etc.; it does reduce short-circuiting and provides for additional flocculation.
 3. "Distributive/Perforated Centerwell" (tried at Stamford CT, and an industrial site), didn't reduce short-circuiting and didn't improve ETSS. Don't repeat it!
- C. A combination of Crosby peripheral baffle and Crosby cylindrical baffle can be more effective than either individual baffle. See CPE projects at Augusta (ME), a 1997 EPA award-winner; and also at New Haven (CT))
- D. The horizontal peripheral shelf baffles may not improve performance (Atlantic City, Orlando, LA-Hyperion) and they always, always, collect solids on the surface!

- E. (Always?) Use interior baffles in rectangular clarifiers (Esler-Miller baffles)
 1. The right baffle will improve most clarifiers
 2. Beware! The wrong baffle(s) can make them worse !
 3. Two baffles are better than one.
 4. Three baffles can be better than two (Branford, CT).
 5. Four baffles can be even better. (Waterford, NY)
 6. other types of Intermediate baffles (Burbank, CA; Edmonton, Alberta; NYC Wards Island)
- F. Focus on improving the center feedwell to give better flow distribution and minimize inlet turbulence; look for the “L.A.-Hyperion Opposing-Jet EDI” inlet.

XI. SOME INNOVATIONS (Some are good but some are not so good !!)

- A. Stacked rectangular units in parallel:
 1. They will have the same (poor) hydraulic characteristics as most counter-current sludge withdrawal rectangular clarifiers.
 2. Haven't worked well at the Boston project (MWRA-Deer Island) or at Mamaroneck.
 3. Are incredibly difficult to maintain!!
- B. Multiple compartments in series in rectangular clarifiers:
 1. This system is used in Japan's best-performing clarifiers!
 2. Can be approximated by using multiple interior baffles.
- C. End-around / Folded-flow / "Boomerang" configurations:
Worked well at Toronto and at NYC's Hunt's Point plant; may be one of the best configurations for rectangular clarifiers.
- D. Speeding up the sludge collector in circular clarifiers didn't work well in Washington, DC; Burlington, Ont.; Geneva, NY.
- E. Lamellas / tube / trays are not recommended for biological systems.
- F. DEEEEEEP clarifiers: Are they really worth the extra \$\$\$\$\$?
- G. “Standard” tangential port energy-dissipating inlet: this type of EDI is supposed to enhance flocculation and distribution, but it is certainly not living up to it's claims! i.e. The clarifier will still have strong density currents (Orlando; Cedar Rapids; Phoenix, Manchester), maybe even worse currents (Atlantic City; Santa Rosa, L.A.-Hyperion). This standard type of EDI has also caused **premature clarifier failure!!!!** Avoid it or pay the price!!!!
- H. The new LA-EDI inlet yielded 50% more capacity than any other modification tested with the new 150-ft. diam. LA-Hyperion clarifiers.
- I. **Beware of novel energy-dissipating inlet designs without good supporting field data**
- J. **Beware of the performance projections of CFD models analyses.** They look “pretty” but we have seen EXTREMELY POOR field correlation with too many of them!!! Think the new “GI-GO” meaning “garbage in – gospel out”???

CLOSING THOUGHTS:

- Use the “Comprehensive Process Evaluation” approach to evaluating and improving clarifier performance. i.e. Identify all the performance-limiting factors in the Design / Operation / Maintenance / and Management of the biological system as well as in the clarifier system. There are usually several of these factors present that are limiting the clarifier's performance. Your challenge is to find them, prioritize them and then optimize them!
- Making your existing clarifiers (typically with a 20% to 30% hydraulic efficiency) more efficient is much more cost-effective than simply adding more of the same inefficient clarifiers! Always start by considering that your existing clarifiers are units with a money-saving potential !! Your job is to maximize that potential!
- Take advantage of the valuable operational and design information that can be gained by a thorough field stress test of any existing clarifiers. See chapter 7 of the WEF MOP on “Clarifier Design” for the field evaluation techniques that YOU CAN DO!
- Don't forget your primary clarifiers! These units are also affected by many of the same conditions that cause problems in secondary clarifiers. Remember this is where you can remove BOD most economically and where you often have real opportunities to capture more materials for recycle and re-use. Improvements in primary clarifier performance will pay multiple \$\$ dividends esp. in energy savings!!
- Take advantage of automatic sludge blanket detectors and probe-type low-level effluent TSS meters for on-line surveillance and control.
- Wherever possible, provide “spill tanks” for unexpected dumps, and equalization of influent flows and sidestream loadings!

Remember There are a lot of good ideas here and elsewhere for your clarifiers. However, you'll never know if they're right for you unless you try them! Just go for it!!!

Note: This outline is presented with extreme gratitude and appreciation for the good work begun in the 1970's and 1980's by the late Bob Crosby. His insight and ingenuity and principles and helpful, sharing nature have always been an inspiration for our work.

This outline also recognizes the many contributions from the experiences of hundreds of talented operators and engineers who have shared their incredible ideas and awesome findings with us!!!