Outline: Advanced Activated Sludge Process Control and Optimization

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Day 1—Begin

I. Introduction
   A. Opportunity: Environment—Energy—Economics
   B. WWTP overview
      1. Liquid treatment train
         a. Influent
         b. Effluent
      2. Solids treatment train
         a. Biosolids
         b. Recycle flows
      3. A manufacturing plant
      4. Optimization and mission of WWTP operators: Remove pollutants from the incoming water—while complying with all permits—and convert them to save, disposal biosolids as sustainably and cost effectively as possible.
   C. Biochemical oxygen demand (BOD)—discussion
   D. Total suspended solids (TSS)—discussion
   E. Primary treatment
      1. Entering TSS
         a. Settleable TSS (TSS_{set}) to the primary sludge
         b. Non-settleable TSS (TSS_{non}) to the primary effluent
      2. Entering BOD
         a. Soluble BOD (sBOD)
         b. Particulate BOD associated with settleable TSS ($pBOD_{set}$)
         c. Particulate BOD associated with non-settleable BOD ($pBOD_{non}$)
         d. Settleable BOD = $pBOD_{set}$
         e. Non-settleable BOD = sBOD + $pBOD_{non}$
      3. Organic TSS (i.e., TSS_{org} or VSS) same material as pBOD
      4. Non-settleable TSS/BOD test—description
      5. Primary removal efficiencies
         a. $E_{TSS} = (TSS_{PI} - TSS_{PE})x100\%/TSS_{PI}$
         b. $E_{BOD} = (BOD_{PI} - BOD_{PE})x100\%/BOD_{PI}$
         c. $E_{TSSmax} = (TSS_{PI} - TSS_{non})x100\%/TSS_{PI}$
         d. $E_{BODmax} = (BOD_{PI} - BOD_{non})x100\%/BOD_{PI}$

e. Maximum performance defined—maximum performance defined by wastewater characteristics

6. BOD a measure of organic carbon
7. Introduction of activated sludge—two unit processes with very different process objectives
   a. Aeration basin
   d. Secondary clarifier

Day 1—Morning Break

II. Activated sludge aeration basin

A. Fate of organic carbon in an activated sludge system
   1. Maintenance energy: energy is attained by the oxidation of organic carbon to carbon dioxide (CO_2—inorganic carbon) and respired
   2. Growth: organic carbon is converted from one form (influent BOD) to another (biomass or MLVSS) when used for growth

B. Aeration basin process objective: To convert particulate and soluble organics (i.e., BOD) into a biomass (MLVSS) that is easily separated from the treated water
   1. Conversion
   2. Separability

C. Making sure process objective is being met
   1. Must be able to measure degree of organic conversion
   2. Must be able to measure how easily the biomass separates for the treated water

D. Conversion
   1. sBOD in mixed liquor exiting the aeration basin is indirect measure of how much conversion has occurred
   2. sBOD test described

E. Separability
   1. Separability defined: A biomass that is easily separated from the treated water must flocculate well, must settle at a reasonable rate, and must compact ("compress") to a sufficient degree
   2. Modified settleometer test begins with flocculation step
      a. SSV_5 = settling parameter
      b. SSV_{30} = compaction parameter
      c. TSS_{sup} (i.e., supernatant TSS) = flocculation parameter

Day 1—Lunch

F. Factors affecting conversion
   1. Must have environment conducive to biological growth
      a. Adequate DO for aerobic growth
      b. Overabundance of all nutrients
      c. Absence of toxic substance

d. Good mixing

e. Neutral pH

f. Growth friendly temperature

g. Adequate detention time

2. Conversion happens with little operator input

3. Don't conclude from high secondary clarifier effluent BOD concentrations that there is a problem with conversion; more likely have a sludge settleability problem

G. Factors affecting sludge quality (i.e., ease of separation, how a sludge flocculates, settles, and compacts)

1. Mixed liquor DO concentration (controlled by air flow rate)

a. Short- and long-term effects of low-DO

b. "Adequate" mixed liquor DO concentration defined in terms of organics loading and specific oxygen uptake rate

c. Using field oxygen uptake rate test to determine where treatment is complete

2. MLSS concentration (controlled by WAS flow rate and on-line aeration basin volume)

a. MLSS concentration a response variable not a control variable

b. Design equation and variable described

c. SRT control is paramount—make it work

d. Taking aeration basins on and off line

3. Biological growth rate (controlled by WAS flow rate)—SRT controls growth rate, too

4. Filaments (controlled by many things)

H. Difference between troubleshooting and process control

1. Troubleshooting is getting out of trouble

2. Process control is staying out of trouble

Day 1—Afternoon Break

III. The other nutrients

A. Ammonia removal

1. Ammonia (NH_3) and ammonium (NH_4^+) in chemical equilibrium dependent upon temperature and pH

a. Unionized NH3 is very toxic to fish

b. Nitrogenous oxygen demand lowers DO in receiving waters

2. Nitrification is the oxidation of NH_3/NH_4^+

a. Ammonia oxidizing organisms (AOOs, e.g., *Nitrosomonas*) oxidize ammonia/ammonium to nitrite (NO_2^-)

b. Nitrite oxidizing organisms (NOOs, e.g., *Nitrobacter*) oxidize nitrite to nitrate (NO_3^-)

c. AOOs and NOOs have a slow growth rate so need a long SRT

        d. Nitrification is an all-or-none phenomenon that is temperature dependent
        e. Uses a lot of oxygen: 4.6 lb of O_2 for every pound of NH_3/NH_4^+ oxidized
        f. DO inhibition of nitrifiers
    B. Nitrogen removal
        1. Nitrogen is a nutrient
        2. Nitrification then denitrification
        3. Denitrification is reduction of nitrate to nitrogen gas and requires the presence of organic carbon (i.e., BOD)
        4. Anoxic define: DO is absent, NO_3^- is present
        5. Typical N/DN plant layout
        6. mg NH_3/L versus mg NH_3-N/L
    C. Phosphorus removal
        1. Phosphorus (often measured as phosphate (PO_4)) is a nutrient
        2. Phosphorus removal is different than nitrogen removal: "trick" certain bacteria ("phosphorus accumulating organisms" or PAOs) into storing more phosphorus than normal then waste them from the system
        3. Role of volatile fatty acids (VFAs)
        4. Typical nutrient (N and P) removal plant layout
        5. mg P/L versus mg PO_4/L

Day 2—Begin

IV. Energy, self-sufficiency, and optimization
    A. Kan, S.J., K.P. Olmstead and T.A. Allbaugh (Dec. 2010), "Four steps to energy self-sufficiency," Water Environment and Technology, 46-49)
    B. The four steps
        1. Commitment
        2. Energy generation
        3. Process energy conservation
        4. Assessment and plan-checking
    C. Chemically enhanced primary treatment
    D. Lowest SRT operation
    E. Turn down air where not needed
    F. The Goal
        1. Maximize throughput by ensuring as much excess plant capacity as possible is available at any given time
        2. Minimize inventory by minimizing the mass of solids residing in each and every process unit at all times (except anaerobic digesters)
        3. Minimize operating costs by doing the other two
        4. Case study

Day 2—Morning Break

V. Activated sludge secondary clarifier

- A. Ability to separate biomass after conversion of influent BOD is key to treatment
- B. Process objective of secondary clarifier: to remove settleable solids
- C. Process objective of secondary clarifier does NOT include "thickening of the underflow;" trying to thicken RAS in secondary clarifiers is root cause of many problems
  1. Operators try to achieve unachievable RAS concentrations
  2. Denitrification—an operational problem when it occurs in the secondary clarifier
  3. Secondary phosphorus release
  4. Deterioration of sludge quality
- D. Equation describing RAS TSS (TSS_{RAS})concentration developed from solids mass balance around secondary clarifier; TSS_{RAS} a function of
  1. RAS flow (Q_{RAS})
  2. Influent flow (Q) with constant Q_{RAS}
  3. Q_{RAS}/Q with flow-proportional Q_{RAS} control
  4. MLSS concentration
  5. TSS_{RAS} very predictable; can't thicken biological solids
- E. TSS_{sup} from modified settleometer test represents the minimum secondary clarifier effluent TSS concentration possible given sludge quality
  1. Should be less than 10 mg/L (indicative of "good biology")
  2. Secondary clarifier achieving its process objective if secondary effluent TSS (TSS_{EFF}) ~ TSS_{sup}
  3. Generally four reasons why TSS_{EFF} > TSS_{sup}
     - a. Denitrification
     - b. Poor flocculation
     - c. Poor secondary clarifier hydraulics
     - d. High sludge blankets

Day 2—Lunch

- F. Six factors define secondary clarifiers performance and capacity
  1. Influent flow
  2. RAS flow
  3. Secondary clarifier surface area
  4. MLSS concentration
  5. Sludge quality
  6. Secondary clarifier hydraulic characteristics
- G. State point analysis
  1. Considers the first five factors in list

2. Derived and explained
    a. Graphical
    b. Axes defined
    c. Overflow rate operating line—slope equal to surface overflow rate (SOR)
    d. Underflow rate operating line
        i. Slope equal to negative of Q_{RAS}/A
        ii. Solids loading rate
        iii. TSS_{RAS} concentration
        iv. Underloaded
        v. Overloaded
        vi. Critically loaded
    e. State point
    f. Settling flux curve—defined by sludge settling characteristics
    g. Review and examples

Day 2—Afternoon Break

3. MLSS concentration can't be controlled by Q_{RAS} unless a sludge blanket is allowed to form in the secondary clarifier or if a sludge blanket already exists in the secondary clarifier
4. System TSS_{RAS} concentration versus 30-minute settled MLSS concentration and how the mixed liquor "compacts"
5. Optimum RAS flow is lowest RAS flow possible that does not result in a sludge blanket during highest flow of the day; requires two considerations
    a. How the sludge settles which determines the location of the settling flux curve
    b. How the sludge compacts which determines the maximum TSS_{RAS} concentration possible