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ON-DEMAND WASTEWATER LIBRARY

WASTEWATER OPERATIONS FACT SHEET

NUTRIENT REMOVAL

	Nitrogen	Phosphorous
Influent Parameters	■ Expressed as N ■ Total Kjeldahl nitrogen (TKN) = Ammonia-nitrogen (NH_3-N) + Organic Nitrogen ■ Total inorganic nitrogen (TIN)= NH_3-N + Nitrite-nitrogen (NO_2-N) + Nitrate-nitrogen (NO_3-N) ■ Total nitrogen (TN) = TKN + NO_2-N + NO_3-N ■ 23 to 69 mg/L as N in influent	■ Expressed as P ■ Orthophosphate and condensed phosphates are soluble ■ Organic phosphate may be soluble, colloidal, or particulate ■ 6 to 8 mg/L as P in influent typical ■ Polyphosphate and organic phosphates converted to orthophosphate during biological treatment
Removal Methods	■ Assimilative uptake for biomass growth ■ 15 to 30% N removed by assimilative uptake ■ Biological nitrification, NH_3-N < 1 mg/L ■ Biological denitrification, NO_3-N < 5 mg/L	■ Assimilative uptake for biomass growth ■ Approximately 1 mg/L P removed by assimilative uptake for every 100 mg/L BOD_5 ■ Chemical phosphorus removal, P <0.03 mg/L ■ Enhanced biological phosphorus removal (EBPR) < 1.0 mg/L P ■ Methods often used in combination

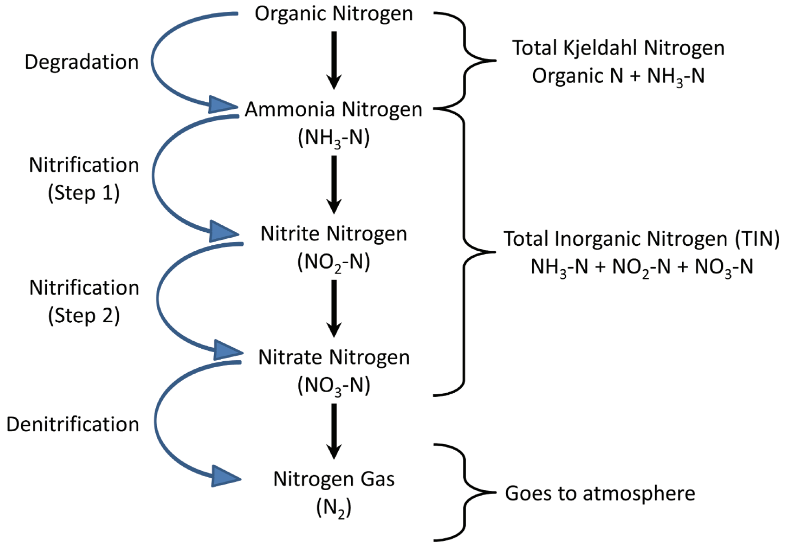

Figure 1 Nitrogen Species in Wastewater

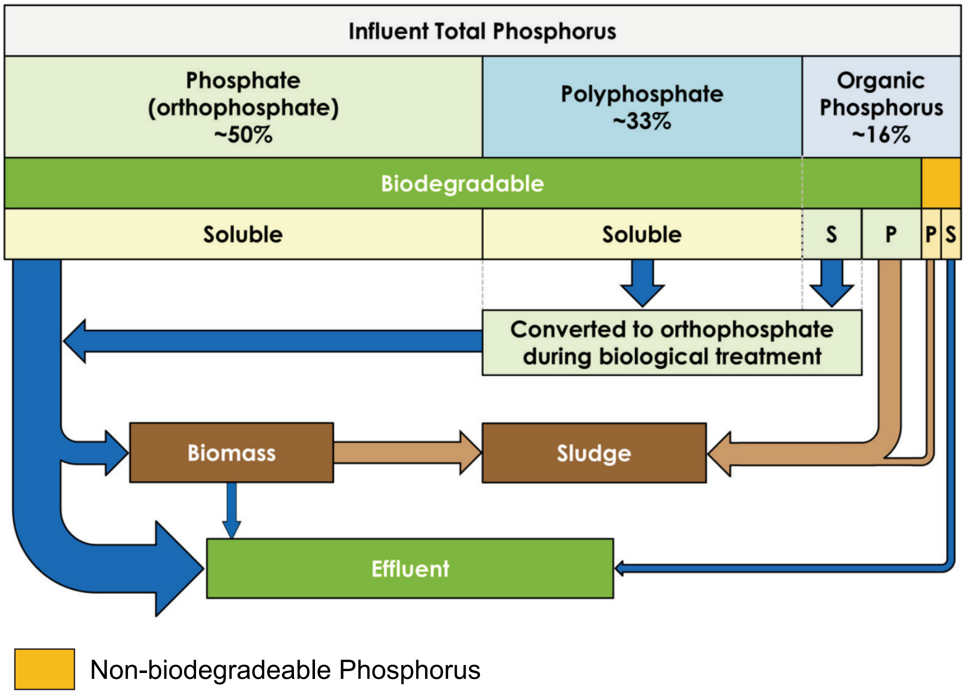

Figure 2 Phosphorus in Wastewater Treatment (S = soluble, P = particulate; this figure shows the fate of phosphorus in secondary treatment processes like activated sludge unless specific steps are taken to remove it) (Reprinted with permission by Indigo Water Group)

	Nitrification	Denitrification
Stoichiometry	■ Nitrification is a two-step process; the ammonia-oxidizing bacteria (AOB) convert ammonia to nitrite and the nitrite-oxidizing bacteria (NOB) convert nitrite to nitrate ■ Converting 1 mg/L of NH_3-N to NO_3-N consumes 4.57 mg/L of dissolved oxygen (DO) and 7.14 mg/L of alkalinity as calcium carbonate ($CaCO_3$) ■ The AOB and NOB grow 10 to 20 times slower than heterotrophic bacteria ■ Only 0.10 g of new bacteria is produced per g of NH_3-N converted to NO_3-N	■ Denitrification converts nitrate to nitrogen gas ■ Many different facultative heterotrophic bacteria can denitrify ■ DO concentrations as low as 0.3 mg/L can inhibit denitrification ■ Converting 1 mg/L of NO_3-N to nitrogen gas (N_2) requires 4 mg/L of influent five-day biochemical oxygen demand (BOD_5) and generates 3.57 mg/L of alkalinity as $CaCO_3$ ■ Nitrate produced is the equivalent of 2.86 mg/L of DO when recycled to an anoxic zone ■ Methanol and other organic compounds increase the amount of nitrate removed; between 2.7 and 3.3 mg/L of methanol is needed for every 1 mg/L NO_3-N ■ Denitrification reduces sludge yield ■ Yield depends on carbon source

	Nitrification	Denitrification
Process Variables	■ The aerobic solids retention time ($\mathrm{SRT}_{\mathrm{aerobic}}$) is the most important process control variable for activated sludge processes ■ SRT is highly temperature dependent ■ Organic loading rate (OLR) is the most important variable for fixed-film processes ■ Soluble BOD_5 must be less than 15 mg/L for nitrification in biofilms ■ DO concentrations of 2 mg/L help ensure maximum nitrification rates in activated sludge processes ■ Low DO may cause nitrite lock ■ Nitrification rates are highest between pH 7.5 and 8.0, but nitrifiers can acclimate to lower pH ■ pH inhibits nitrification by limiting the availability of un-ionized ammonia (NH_3) ■ A minimum alkalinity concentration of 50 mg/L as CaCO_3, and preferably 100 mg/L, is needed to prevent pH drop ■ AOB can't store ammonia and don't grow quickly enough to take advantage of transient ammonia loads	■ Denitrification is limited by the availability and type of organic carbon ■ Anoxic tanks or zones contain nitrate but no oxygen ■ Nitrate is produced in areas with aerobic conditions and must be returned to areas with anoxic conditions ■ The specific denitrification rate (SDNR) is how fast denitrification occurs ■ SDNR depends on the organic carbon to nitrate ratio ■ The higher the food-to-microorganism ratio (F/M), the faster denitrification will occur ■ Denitrification is faster with soluble BOD than particulate ■ Pre-anoxic zones denitrify faster than post-anoxic zones because more organic carbon is available ■ Activated sludge processes with a single anoxic zone or basin can achieve total effluent nitrogen of <10 mg/L as N or up to 85% removal of the total oxidizable nitrogen in the influent ■ Increasing the internal mixed liquor recycle (IMLR) will increase nitrate removal when organic carbon is available
Process Control	■ Retain biomass in the process long enough to allow the nitrifying bacteria to reproduce and build a stable population ■ Use safety factor to prevent moving above and below the minimum $\mathrm{SRT}_{\mathrm{aerobic}}$ required to prevent nitrite accumulation ■ Reduce competition from heterotrophic bacteria by minimizing organic loading rates ■ Ensure adequate supplies of ammonia, DO, and alkalinity ■ Manage recycle streams to keep ammonia loading as consistent as possible	■ Add supplemental BOD to maintain a BOD to NO_3-N ratio of at least 4:1 ■ For activated sludge processes, increase the IMLR to decrease effluent NO_3-N ■ Recycle ratios typically less than 400% of influent flow ■ Ensure the anoxic zone remains anoxic by minimizing DO recycled in the IMLR and return activated sludge ■ Keep anoxic zone oxidation–reduction potential (ORP) between 250 and 150 mV ■ ORP readings are dependent on electrode type and fill solution used ■ For fixed-film processes, increasing recycle flow increases denitrification

Chemical Precipitation

Stoichiometry

- Metal salts combine with orthophosphate ion to form insoluble compounds that come out of solution (precipitate)
- Aluminum sulfate (alum), ferric chloride, and sodium aluminate are the most commonly used chemicals for phosphorus precipitation
- Weight ratios are calculated from balanced chemical equations; the stoichiometric dose to precipitate of 1 mg/L of phosphate as P requires
  - ❑ 0.87 mg/L aluminum ions, or
  - ❑ 1.8 mg/L ferric iron ions, or
  - ❑ 9.6 mg/L alum, or
  - ❑ 2.64 mg/L sodium aluminate, or
  - ❑ 5.24 mg/L ferric chloride
- Side reactions consume aluminum and iron ions by forming hydroxides
- To reduce effluent P to 1 mg/L, 1.5 to 2 times the stoichiometric dose is typically needed
- To meet ultra-low effluent P limits, 6 to 7 times the stoichiometric dose may be needed
- Chemical precipitation increases sludge production

Process Variables

- Aluminum and iron addition consumes alkalinity (mg/L as $CaCO_3$)
  - ❑ 1 mg/L alum consumes 0.5 mg/L
  - ❑ 1 mg/L ferric chloride consumes 0.56 mg/L
- Supplemental alkalinity may be needed
- Sodium aluminate increases alkalinity
- Wastewater pH affects the amount of precipitate formed
- Optimum pH range depends on the chemical used
  - ❑ Alum – 5.5 to 6.5 SU
  - ❑ Ferric chloride – 3.5 to 5.0 SU
  - ❑ Both work well up to pH 6.5
- Ferrous iron converts to ferric iron in aerobic processes
- Precipitation in anaerobic processes is best at pH 8
- Improve P removal with rapid chemical mixing and longer contact times
- Iron compounds are added at different locations to achieve different process objectives, including odor and corrosion control, improvement of clarifier performance, reducing struvite formation, and precipitating phosphorus
- Aluminum compounds are used to remove phosphorus and improve clarifier performance

Process Control

- Perform jar tests followed by full-scale testing to confirm dosing calculations
- Add chemicals as far upstream as possible from the precipitate removal to maximize contact time
- Add polymer as far downstream of metal salt addition as possible
- Control dosages upstream of the primary clarifier to prevent
    - ☐ Excessive BOD_5 removal,
    - ☐ Excessive alkalinity consumption, and
    - ☐ Inhibition of nitrification or denitrification in the secondary treatment process
- Minimize effluent total suspended solids (TSS)

Enhanced Biological Phosphorus Removal

Stoichiometry

- MLSS is cycled between anaerobic and anoxic/aerobic conditions to promote the growth of phosphate-accumulating organisms (PAOs)
- *Accumulibacter* and *Tetrasphaera* perform luxury uptake of phosphorus
- Phosphate stores energy as poly-P
- Under anaerobic conditions, poly-P is used to take up volatile fatty acids (VFAs)
- VFAs are stored as poly-b-hydroxybutyrate (PHB)
- Magnesium and potassium ions neutralize phosphate ions and make it easier to pass them through the cell membrane
- Fermentation occurs in the anaerobic zone
- *Tetrasphaera* performs fermentation when ORP is below –300 mV
- Luxury uptake occurs in the anoxic and aerobic zones

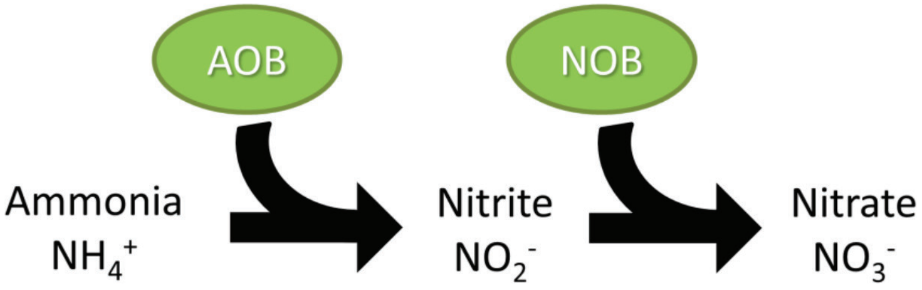

Figure 3 Nitrification Sequence (Reprinted with permission by Indigo Water Group)

Process Variables

- The organic carbon-to-P ratio is the most important process control variable for EBPR
- Organic carbon must be available as VFAs or readily biodegradable five-day carbonaceous BOD ($CBOD_5$)
- VFAs are produced in the collection system and anaerobic zone
- VFAs may also be produced by fermenting sludge in an active primary or other location
- pH below 6.5 in the anaerobic zone inhibits EBPR
- pH below 6.9 in the anoxic/aerobic zones inhibits EBPR
- A minimum SRT of 3 days is needed to maintain PAOs in an activated sludge process

Process Control

Process control for EBPR includes

- Ensuring an adequate supply and variety of VFAs,
- Preventing DO and nitrate from reaching the anaerobic zone,
- Keeping the ORP below 2300 mV in the anaerobic zone,
- Minimizing TSS in the final effluent,
- Managing recycle loads,
- Avoiding secondary release of P, and
- Minimizing competition from glycogen-accumulating organisms (GAOs)

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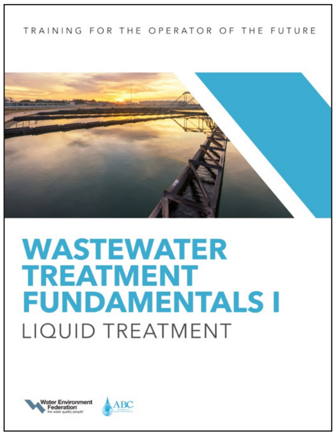

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