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Nitrogen and Phosphorus
The Next Level of Treatment

John R. Buchanan, Ph.D., P. E.
Professor and Extension Specialist
Department of Biosystems Engineering & Soil Science

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INSTITUTE OF AGRICULTURE
THE UNIVERSITY OF TENNESSEE

1

Nitrogen and Phosphorus
The Next Level of Treatment

- Historically
  - the level of treatment provided by wastewater treatment plants depended on what rules where in effect at the time
- Rivers and streams
  - were open sewers
  - are now are becoming fishable and swimmable
- Primary Treatment
  - liquid/solid separation
- Secondary Treatment
  - oxygen demand removal
- Tertiary Treatment
  - reduction of nutrients
- Quaternary Treatment ???
  - pharmaceuticals????

2

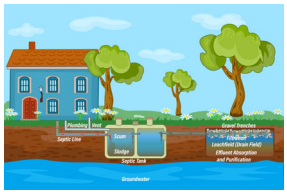
Soil-Based Wastewater Treatment

- In general
  - We are not regulated based on the removal of particular contaminants of the waste stream
- Our job is to separate humans from their wastes
  - thankfully, the soil does a good job of removing the contaminants
- What the soil does not remove
  - moves on to the groundwater

3

Soil-Based Wastewater Treatment

- We have pretreatment
  - liquid/solid separation
- And we have final treatment
  - what happens in the soil
- But it is rare that we are regulated by any particular waste constituent



https://www.searchclaytonncrealestate.com/blog/how-does-a-septic-system-work/

4

Onsite Wastewater Treatment Systems

- We protect the soil interface to ensure that the effluent does not come back to the soil surface
- Use a septic tank for liquid/solid separation
  - we separate out solids because we know that the solids will clog the trench
- If the soil cannot handle the extra organic matter
  - we use aerobic treatment to reduce the BOD
  - we know that excess BOD will clog the trench

5

However,

- As septic system get larger or as we build in environmentally sensitive locations
  - we are starting to see more regulations that are based on individual waste components
  - coliform bacteria (disinfection)
  - nitrate (denitrification)
  - phosphate (chemical precipitation)

6

Regulations are Based on…..

- Safe Drinking Water Act
  - large capacity septic systems – serves 20 or more persons
  - Class V Injection Well
  - potential contamination to drinking water (especially well water)
  - limited to 10 mg/L of nitrate as N at water tap – blue baby syndrome
- Clean Water Act
  - thou shall not cause a condition of pollution to surface waters
  - excess nutrients create eutrophic conditions when groundwater flows into surface waters.

7

Nitrogen and Phosphorus

- Two primary plant nutrients
  - also, important nutrients for humans
- Concern
  - overgrowth algae, cyanobacteria bacteria, and other aquatic plants
    - creates oxygen demand
    - releases toxins into the water

8

Limiting Nutrient Concept

- Between Nitrogen and Phosphorus
  - which one is currently the limiting nutrient in the waterbody
- Have plenty of nitrogen, but very little phosphorus
  - add a little phosphorus and the aquatic system will bloom
  - phosphorus is the limiting nutrient
- Have plenty of phosphorus, but very little nitrogen
  - nitrogen is the limiting nutrient

9

Limiting Nutrient Concept

- Therefore,
  - We need to reduce the amount of the limiting nutrient to prevent algal and bacterial blooms
- Let's start with Nitrogen

10

Nitrogen Cycle

- Atmosphere
  - 78% N_2 gas
- Fixation
  - N_2 to NH_3
- Assimilation
  - Ammonia converted protein
- Ammonification
  - proteins degraded, release ammonia
  - aerobic process
- Nitrification
  - ammonia converted to nitrite, then nitrate
  - aerobic process
- Denitrification
  - nitrate converted N_2 gas
  - anaerobic process

11

Nitrogen Fixation

- Nitrogen gas is "fixed" into inorganic forms
  - by microbes
    - soybean nodules
  - by the Haber-Bosch Process
    - industrial ammonia production

mytakeontoday.wordpress.com

12

Organic Nitrogen

- Plants and some microbes uptake ammonia and nitrate
  - convert to protein and other organic compounds
  - and we consume the organic nitrogen

volksmann.wordpress.com

13

Digestion

- As part of our metabolism
  - we excrete nitrogen compounds
- And
  - now we need to convert the nitrate back to nitrogen gas
  - to prevent excessive inorganic nitrogen

14

Basic Equation for Carbon Conversion

$$\text{Organic Carbon} + O_2 \xrightarrow[\text{microorganisms}]{\text{aerobic}} \text{Energy} + CO_2 + H_2O + \text{Residue}$$

$$+ O_2 \xrightarrow[\text{microorganisms}]{\text{new aerobic}} \text{Energy} + CO_2 + H_2O + \text{Residue}$$

$$+ O_2 \xrightarrow[\text{microorganisms}]{\text{new aerobic}} \text{Energy} + CO_2 + H_2O + \text{Residue}$$

15

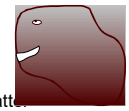
What about Nitrogen?

- A different set of Aerobic microorganisms are needed to start this process of converting nitrogen
- So,
  - more dissolved oxygen is needed
  - and we can provide it
- Problem,
  - some of these microbes are real wimps

16

Autotrophs and Heterotrophs

- The majority of wastewater bacteria
  - heterotrophs
    - carbon source: organic carbon
    - energy source: organic carbon
  - exactly what we need to degrade organic matter
  - divide every 20 to 30 minutes
- Facultative
  - prefer aerobic
- Releases nitrogen as protein is degraded
  - which becomes ammonia



17

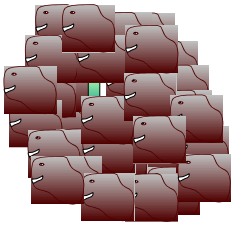
Autotrophs and Heterotrophs

- Nitrifiers
  - chemolithic autotrophs
    - carbon source: inorganic carbon
    - energy source: ammonia & nitrite
  - strictly aerobic
    - need 2 mg/L D.O.
  - divide every couple of days
    - very slow growing
  - In a word, wimps

18

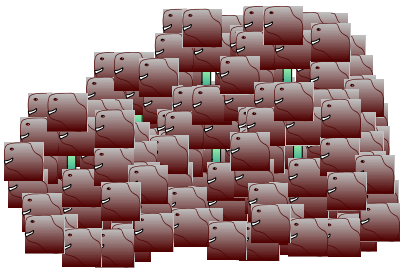
Heterotrophs Outcompete

- For dissolved oxygen
- For nutrients
- All these components must diffuse through the biological floc



19

Growth Ratio: 10^{28} to 2



20

Yet, Nitrification Usually Occurs

- Nitrifying bacteria are pervasive in the wastewater environment
  - they just show up
  - but they do not feel welcome
- Two primary groups
  - nitrosomonas
    - ammonia to nitrite
  - nitrobacter
    - nitrite to nitrate

21

Nitrification

- Organically bound nitrogen is released when the organic compound is oxidized
  - released as the ammonium cation (NH4+)
- Nitrification is a two-step autotrophic process
  - the conversion from ammonium to nitrate

Nitrosomonas

Step 1: $NH_4^+ + 3/2O_2 \rightarrow NO_2^- + 2H^+ + H_2O$

Nitrobacter

Step 2: $NO_2^- + 1/2O_2 \rightarrow NO_3^-$

From Academic Curriculum chapter: *Onsite Nitrogen Removal*, By Stewart Oakley

22

Remember the Acid

- If we do not neutralize the acid
  - then we can depress the pH and stop the process
- We need alkalinity
  - the ability to buffer pH changes
  - in some situations, we may need to add sodium bicarbonate

23

Now, We need to Finish the Job

- Nitrate is plant available nutrient
  - can cause excessive plant growth in surface waters
  - with these plants die off, they cause excessive oxygen demand in the water
    - water can go anaerobic
    - kill off aquatic species
- So, we need to de-nitrify

24

Denitrification

- Denitrification is the conversion of mineral nitrate to nitrogen gas
- The primary bacteria that are responsible for denitrification are facultative
  - can survive in aerobic or anaerobic conditions
  - under anaerobic conditions, the denitrifying bacteria use NO_3^- rather than O_2 as the electron acceptor.

25

Denitrification

- These denitrifying bacteria are also heterotrophic
  - they need organic carbon as an energy source
  - but, we may have already digested most of the organic carbon

26

Denitrification

- Using wastewater as the Carbon Source
- The following unbalanced equation illustrates the process when wastewater or bacterial cell material is used as the carbon source:

Heterotrophic

$$COHNS + NO_3^- \rightarrow N_2 + CO_2 + C_5H_7O_2N + OH^- + H_2O + \text{end products}$$

organic matter — *Bacteria* — *bacterial cells*

27

Biological Denitrification

- Dissolved oxygen must not be present above certain maximum levels
  - or the denitrifying bacteria will preferentially use O_2 for oxidation of organic matter rather than NO^{3-}.
- As a result, the design of anoxic zones is one of the most important factors in denitrification processes.

28

Sulfur Oxidizing Denitrification

- A number of common soil bacteria, such as Thiobacillus denitrificans and Thiomicrosporia denitrificans, are able to reduce sulfur compounds as electron donors and respire on nitrate in the absence of oxygen. A stoichiometric equation for autotrophic denitrification using sulfur as an electron donor is:

$$55S^0 + 20CO_2 + 50NO_3^- + 4NH_4^+ \rightarrow 4C_5H_7O_2N + 55SO_4^{2-} + 25N_2 + 64H^+$$

Sengupta, S. and S. J. Ergas (2006) Autotrophic biological denitrification with elemental sulfur

29

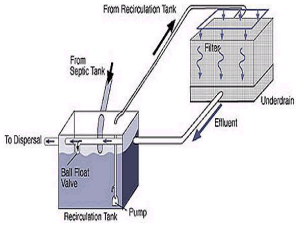
Biological Denitrification

- Issues
  - how do we get anaerobic conditions after working so hard to get aerobic conditions
  - need an organic carbon source for the heterotrophs
  - need to control the acid

30

Recirculation

- Circulate a portion of the aerobically treated effluent back to anaerobic tank
  - no dissolved oxygen
  - plenty of dissolved organic carbon
  - 4 to 1 ratios are common
  - 4 parts recirculated with 1 part being discharge to soil



31

Permeable Reactive Barrier

- Provides carbon to drive denitrification
  - wood chips, saw dust

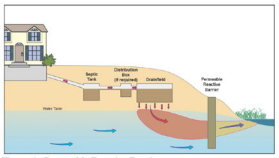


Figure 4. Permeable Reactive Barrier

32

Background

- Packed-bed recirculating media filters
  - Two problems with the name
    - the media doesn't recirculate
    - and the process does not filter
- Common process for small-system wastewater treatment
  - passive aeration
  - fixed film, attached growth microbiology
  - low maintenance
  - larger footprint than activated sludge process
  - withstands shock loadings

33

Not a New Technology

- Packed-bed media filters have been used for many years
  - dependable
  - easy to design and build
  - easy to maintain
- Design is based on wastewater load
  - hydraulic loading (3-5 gpd/ft^2)
  - organic loading (0.002 – 0.008 lb BOD/$ft^2 \cdot d$)

34

Investigated System

- Blount County, Tennessee
- Subdivision
  - STEG
  - approximately 80 homes
    - three bedroom pre-manufactured housing

35

Wastewater Infrastructure

- Lift station
  - collects all the water from STEG
  - transfers water to recirculating packed-bed media filter
- Hines-Pickney sand filter
  - 16,000 gallon per day
  - volume moved through filter is approximately five times the daily inflow
- Subsurface drip irrigation dispersal

36

Specifications

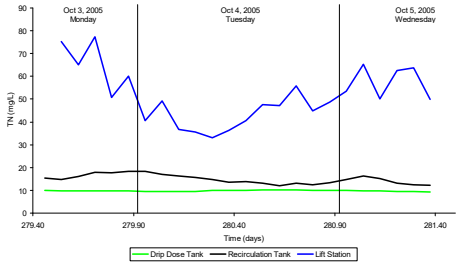
- 6,000 square feet of top surface area
  - 2.5 gallons per day per square foot

37

Gravel-Media Filter
Frequently called a Sand Filter

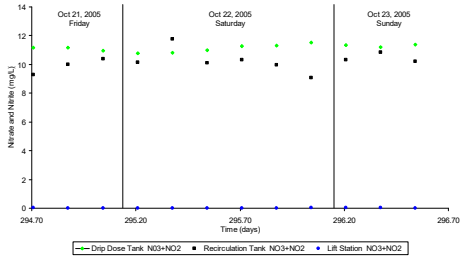
38

Total Nitrogen (TN)



39

Nitrification and Denitrification



40

Preliminary Conclusions

- Sufficient buffering and mixing within system to handle variations in influent strength to produce very constant effluent
- Nitrification was not really a question
- Denitrification is occurring

41

Denitrification

- It is a natural process
  - but it is not guaranteed to occur
- We have to control oxygen
  - aerobic then anaerobic
- We have to control organic carbon
  - must leave some carbon for denitrification
- We must control pH
  - nitrification creates acidity

42

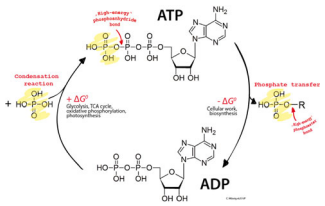
For Predictable Denitrification

- Wastewater system must be maintained by professional service providers
  - measure pH
  - measure DO
  - measure alkalinity
  - and measure nitrates

43

What about Phosphorus

- The reactive form is ortho-phosphate – PO_4^{3-}
- Very important plant and animal nutrient
  - DNA, RNA, ATP (adenosine triphosphate)
  - 80% of phosphate in our bodies in teeth and bones



44

Phosphorus Cycle

- Weathering
  - of phosphate rock and minerals
- Absorption
  - by plants and animals
- Decomposition
  - phosphate is released back into environment
- Immobilization and precipitation
  - binds with aluminum, iron, calcium in soils and sediments

45

Basically…..

- For removing phosphorus from wastewater
  - we have two options (neither of which is good)
- Advanced Biological Treatment
- Chemical Precipitation

46

Advanced Biological Treatment

- Activated sludge
  - using microbes that have a luxurious consumption of phosphate
  - they uptake phosphate in excess of metabolic requirement, and store it as part of cellular mass
  - harvest the biomass and remove the phosphorus out of the water
- Not a good option for small systems
  - must maintain a high MLSS concentration

47

Chemical Precipitation

- Add dissolved aluminum, iron, or calcium to effluent
  - metals will bind with phosphate
  - form an insoluble precipitant
  - results in a phosphate-rich sludge at bottom of tank
- Who is going to make sure the chemical injection system is functional
- Who is going to clean out the sludge
- Who will accept the sludge when we clean it out

48

For Small Wastewater Systems

- If (when) we are regulated on phosphorus
  - chemical precipitation of phosphorus before the effluent is placed below the surface will be our go-to solution
- Great opportunity for service providers
  - install a separate tank just for the precipitation reaction
  - will make it easier to withdraw the sludge without having the pump out the whole system

49

Nutrients in Wastewater

- It is not a new concept – we have been using our wastes as fertilizer for many thousands of years
- Excessive nutrients cause overgrowth of aquatic plants and can be toxic in drinking water

50

Removing Nutrients from Wastewater

- Difficult for small systems
  - irregular flows
  - irregular wastewater strength
  - hard to predict how much of the nutrients will be removed by the soil
- A little easier for large systems
  - consistent flows
  - consistent wastewater strength

51

My Personal Philosophy

- If you have a limiting waste constituent
  - remove it before placing effluent in soil
- Denitrification
  - recirculation systems
- Phosphorus removal
  - chemical precipitation
- Pathogens
  - disinfection

52

Thank You!

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53