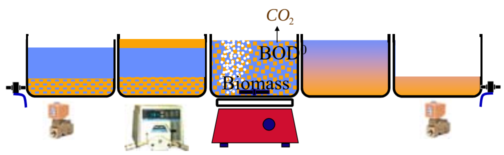


Nutrient Removal Project

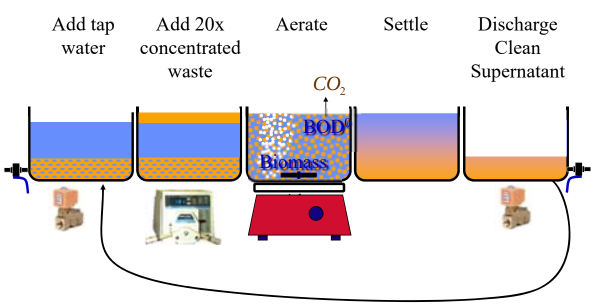
- Project Expectations
- Project rationale (context)
- Nitrogen Removal
- Sequencing Batch Reactor Operation
- Software that makes decisions
- Research Ideas

Project Expectations

- 3 weeks of plant operation 4 hours per week outside of class
- Data collection and data analysis used for plant control (evidence of good engineering)
- Maintain good records of what you did and what you learned
- Collaboration between teams is encouraged
- What is success? – measure oxygen uptake rate as a function of time!

SBR design

SBR OPERATION for Activated Sludge



Plant Flow Rate

- HRT of approximately 6 hours
- MLVSS (mixed liquor volatile suspended solids)
  - 3000 mg/L using clarifier
- 4 L tank therefore ___ L/day (per plant)

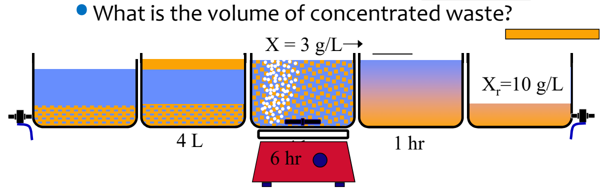
16 L/d * 6 weeks * 7 d/week * 8 plants = 5400 L

Suspended Solids Targets and Measurements

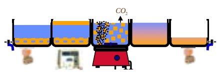
- Key to reactor success is keeping adequate MLVSS in the reactor
- Solids retention time is approximately 10 days
- Target MLVSS of approximately 3 g/L
- If reactor volume is 4 L then waste ___ g/day
- Effluent concentration of solids needs to be very low

SBR Feed and Waste Volumes

- What is the recycle volume? ________
- What is the volume of waste (tap+concentrate) ________
  - What is the volume of tap water?
  - What is the volume of concentrated waste?



SBR States and Exit Decision Variables



State	Exit decision variable
• Fill with water	____________
• Fill with waste	____________
• Aerate	____________
• Settle	____________
• Drain	____________

Synthetic Feed Composition

Stock 1 (100x) refrigerator

____

____

____

Stock 2 1000x ______

Stock 3 1000x

Compound	Chemical Formula	Molecular Weight g/mol	Concentration mg/L
Starch		~40,000	84.40
Casein		~30,000	125.00
Sodium acetate	$C_2H_3O_2Na{\cdot}3H_20$	136.1	31.90
Capric acid	$C_{10}H_{20}O_2$	172.3	11.60
Ammonium chloride	NH_4Cl	53.5	75.33
Potassium phosphate	K_2HPO_4	174.2	6.90
Sodium hydroxide	$NaOH$	40.0	1.75
Glycerol	$C_3H_8O_3$	92.1	12.00
Magnesium sulfate	$MgSO_4{\cdot}7H_2O$	246.5	69.60
Sodium molybdate	$NaMoO_4{\cdot}2H_2O$	241.9	0.15
Manganese sulfate	$MnSO_4{\cdot}H_2O$	169.0	0.13
Cupric sulfate	$CuSO_4{\cdot}4H_2O$	249.7	0.08
Zinc suflate	$ZnSO_4{\cdot}7H_2O$	287.5	0.48
Calcium chloride	$CaCl_2{\cdot}2H_2O$	147.0	22.50
Iron chloride	$FeCl_3{\cdot}6H_2O$	270.3	18.33
Cobalt chloride	$CoCl_2{\cdot}6H_2O$	237.9	0.42

Feed Characteristics

- Completely soluble at feed concentration
- 325 mg/L COD (Chemical Oxygen Demand)
- 40.9 mg/L nitrogen

Organic Feed Lines

- What will happen if the organic feed line holds a high concentration of organics at room temperature for several weeks?
- Why might this be a problem?

  ____

- How can you solve this problem?

  ____

Not necessary for 1 week of operation

Dissolved Oxygen Control

- Suppose the fill cycle just ended
- How could you set the initial aeration rate?
- How could you correct the aeration rate?
- What are some potential control strategies?
  - _____________________
  - _______________________
  - ________________________________

On-off controller is available as an external function

Project Constraints

- 1 peristaltic pump
- 6-24 V devices (Valves, stirrer)
- 1-110 V device can be turned on and off using a 24 V control
  - The 110 V device can be controlled by a 24 V control that also controls a valve
- 1 pH sensor, 1 DO sensor, 4 pressure sensors

This Week's Objectives

- Build a sequencing batch reactor that includes:
- Aeration
  - Cycled valve in air line using accumulator
- Stirring
- Automated Empty/Fill-Dilute cycle
- Configured sensors, set points, rules, and states

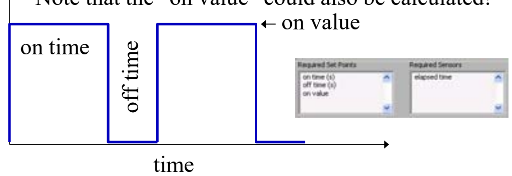
This Week's Objectives (continued)

- Add the DO probe
- Run Plant in automatic mode
- Run your plant with fake synthetic waste!
- Manually add sodium sulfite to mimic oxygen demand and see how your plant responds to low oxygen levels
- Eliminate all leaks!
- Ready for waste Wednesday after break

Duty Cycle Function

\\enviro\enviro\Software\Process Controller methods\math functions\duty cycle.vi

Note that the "on value" could also be calculated!



How could you set up the process controller to measure oxygen uptake rate using this code?

Startup Checklist

- Verify that all sensors are working
- Replace DO membrane
- Calibrate dissolved oxygen probe in saturated water
- Fill reactor with mixed liquor from IWWTP activated sludge tank
- Fill organic waste bottle with organic waste
- Measure MLVSS (mixed liquor volatile suspended solids)
- Begin in settle phase (make sure time is long enough)

Standard Operating Procedure (SOP)

- What is in the data files?
  - All sensors
  - All variables
- What is in the state log files?
  - Times, states, rule that caused state to change
- How often must you add organic waste in the refrigerator?
- Scrape sides of reactor to keep solids in suspension
- Verify that fill and drain times are reasonable (no clogged valves)
- Replace DO membrane (weekly)

PROCESS CONTROL SOFTWARE

- Data Acquisition
- Process Control
  - Make decisions based on data
  - Send command to ProCoDA hardware to Control valves, pumps, stirrers
- Data logging to file (and variable set points)
- Plot data on graph
- Handle Operator Commands

Organize your Tasks

- Goal is sequencing batch reactor with controlled aeration
- What tasks must you accomplish?
- How can you maximize your productivity?

Proportional Integral Derivative Control

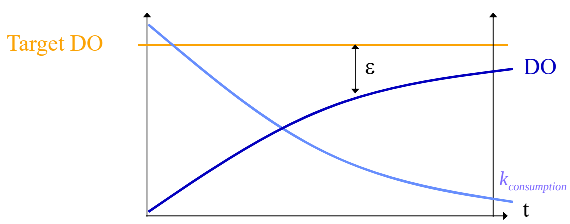
$$u(t) = K_c\left(\varepsilon + \frac{1}{T_I}\sum \varepsilon \cdot \Delta t + T_D\frac{\Delta\varepsilon}{\Delta t}\right)$$

K_c is controller gain (tuning parameter)
T_I is the integral time (tuning parameter)
T_D is the derivative time (tuning parameter)
$\Delta\varepsilon/\Delta t$ is the error rate of change (Note that this is the same as the dissolved oxygen concentration rate of change)
$\sum \varepsilon \cdot \Delta t$ is the area under the curve of the error as a function of time.
$u(t)$ is the airflow rate that the controller sets

The **Error (ε)** is the difference between the **Process Variable** and the desired **Setpoint**. The controller uses the proportional gain, $\mathbf{K_c}$, the integral time constant, $\mathbf{T_i}$, and the derivative time constant, $\mathbf{T_d}$, to determine an **Output** which drives the **Error** to zero.

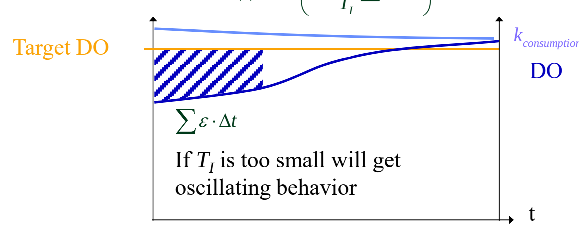
Proportional

$$u(t) = K_c\varepsilon$$



Proportional Integral

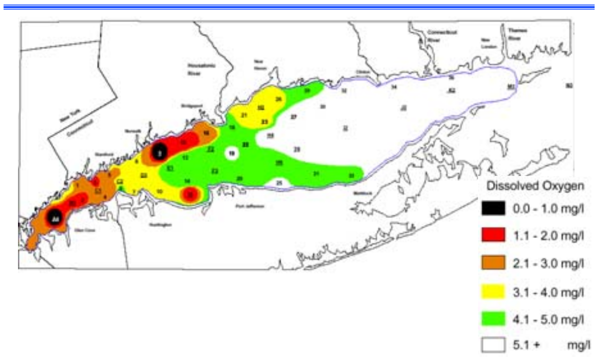
$$u(t) = K_c\left(\varepsilon + \frac{1}{T_I}\sum \varepsilon \cdot \Delta t\right)$$



Global Need for Better Nutrient Management

- Coastal dead zones
- Fish kills
- Migratory routes blocked
- Loss of diverse ocean ecosystems
- Human Population
- Agribusiness

Long Island Sound: August 1998



Long Island Sound Study

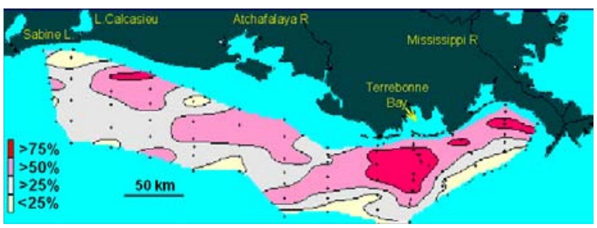
- The LISS adopted a plan in 1998 to reduce nitrogen loads from human sources in the Sound by 58.5%
- The greatest human sources of nitrogen in the Sound are from wastewater treatment plants discharging into waters within the Long Island Sound watershed, or directly into the Sound itself
- A major component of the nitrogen reduction plan includes the need for wastewater treatment upgrades that emphasize nitrogen removal
- As a result of BNR upgrades to STPs, there has been a reduction of 19.2 percent in nitrogen loading to Long Island Sound from STPs in the 1990's (10% reduction of total)

http://www.longislandsoundstudy.net/pubs/slides/soundhealth/ch2.pdf

Gulf of Mexico

- The "Dead Zone", or hypoxic zone, is a 7,000 square mile expanse of oxygen-depleted waters that cannot sustain most marine life
- Human activity has resulted in a significant increase in nitrogen flux
- Nitrogen sources include
  - Industry
  - Municipal waste water treatment
  - Agriculture
    - Fertilizer
    - Livestock manure

Bottom water hypoxia: Frequency of midsummer occurrence 1985-1999



Reducing the Footprint of a Growing Global Population

- Conventional activated sludge process
  - Removes BOD (organic carbon to CO_2)
- Nitrification
  - Removes TKN (organic nitrogen and ammonia to nitrite and nitrate)
  - TKN: Total Kjeldahl Nitrogen (_______________)
- Denitrification
  - Removes nitrite and nitrate by conversion to N_2 gas

NITROGEN REMOVAL $\overset{N_2}{\uparrow}$

- Protect watersheds and coastal areas from eutrophication
- Treatment of high nitrogen wastes
  - Agricultural runoff
  - Feedlot wastewater
  - Centrate from Wastewater Treatment Plants
- Treatment of drinking waters that contain elevated nitrite and nitrate

Requirements for Nitrogen Removal

$$\frac{1}{24}C_6H_{12}O_6 + \frac{1}{4}H_2O \rightarrow \frac{1}{4}CO_2 + H^+ + e^-$$

- Electron Donor
  - Organic (heterotrophs)
    - Organic carbon (BOD) present in the waste
    - Methanol (often added when organic carbon is already depleted)
  - Inorganic (autotrophs)
    - H_2 or reduced sulfur (H_2 can be added using bubbleless membrane dissolution)
- pH
  - Optimal range of 7-8
  - Denitrification produces strong base

$$CH_3COOH + \frac{8}{5}NO_3^- + \frac{4}{5}H_2O \rightarrow \frac{4}{5}N_2 + 2H_2CO_3 + \frac{8}{5}OH^-$$

Denitrification Reactions and Enzymes

- Reaction — Enzyme
- $NO_3^- + 2e^- + 2H^+ = NO_2^- + H_2O$ — Nitrate Reductase
- $NO_2^- + e^- + 2H^+ = NO + H_2O$ — Nitrite Reductase
- $2NO + 2e^- + 2H^+ = N_2O + H_2O$ — Nitric Oxide Reductase
- $N_2O + 2e^- + 2H^+ = N_{2(g)} + H_2O$ — Nitrous Oxide Reductase

- Overall process requires 5 electron equivalents per nitrogen

Role of Oxygen Concentration

- Inhibition of nitrogen-reductase genes
  - Genes are repressed when oxygen concentration exceeds 2.5 – 5 mg O_2/L
  - Denitrifiers can produce reductase at relatively high O_2 concentration
- Inhibition of nitrogen-reductase activity
  - Reaction inhibited when oxygen concentration exceeds a few tenths of a mg O_2/L
  - Denitrification can only occur if oxygen levels are very low somewhere in the reactor!

Reactor Designs for Denitrification

- Activated Sludge
- Biofilm Processes
- One sludge
  - Biomass storage and decay
  - Classical pre-denitrification
  - Simultaneous nitrification with denitrification
- Barnard Process
- Sequencing Batch Reactor

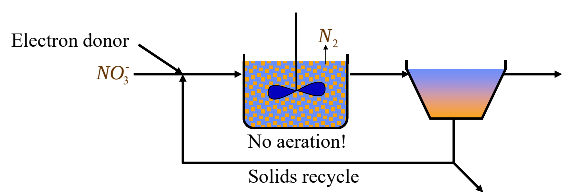
Trick: Reserve some electron donor (organic carbon) for denitrification

Tertiary Denitrification using Activated Sludge

- SRT (5 d) >>HRT ________

$$SRT = \frac{\text{Mass Sludge In System}}{\text{Mass Sludge Leaving System Per Day}}$$

- High cell concentration increases reaction rate

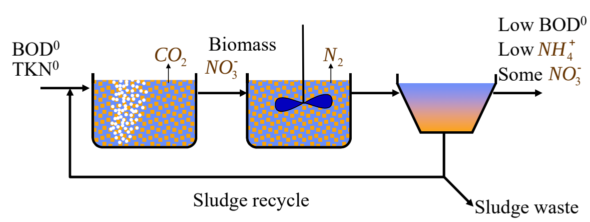


Biofilm Processes

- Submerged fixed beds of rocks, sand, limestone, or plastic media
- Fluidized beds of sand, activated carbon, and pellets of ion-exchange resin
- Circulating beds of a range of lightweight particles
- Membrane bioreactors (membrane supplies H_2 and is the attachment surface)
- HRT can be less than 10 minutes!

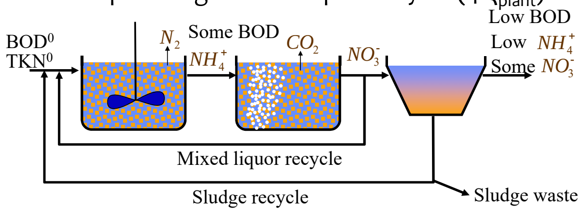
Biomass Storage and Decay

- Uses ________ as electron donor for denitrification
- Slow kinetics of endogenous decay



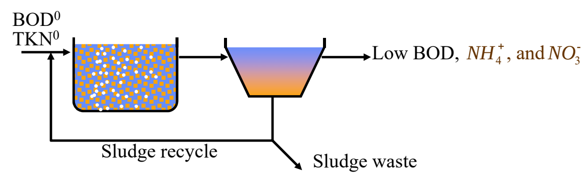
Classical Pre-Denitrification

- Uses ____ as electron donor for denitrification
- Requires high mixed liquor recycle ($4Q_{plant}$)



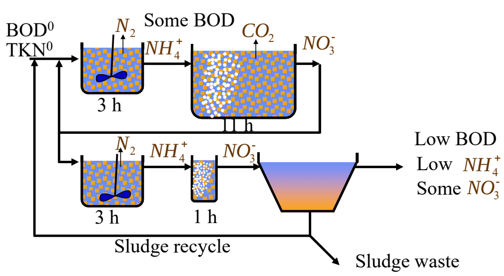
Simultaneous Nitrification with Denitrification

- Uses ____ as electron donor
- Low oxygen levels permit denitrification
- Can achieve 100% N removal!



Barnard Process

- Greater than 90% removal of TKN!



Barnard Sequencing Batch Reactor

- Same process as Barnard carried out in a single tank