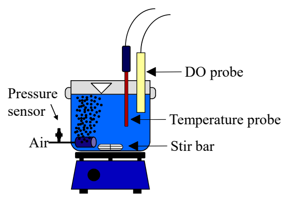
Nutrient Removal Project: Oxygen Requirements

- History of Human Waste
- Nutrient Removal Project
- Dissolved oxygen measurements
- Oxygen Transfer



Excreta Disposal: Land Application

- When population densities were low excreta disposal was an individual problem.
- As cities grew it was no longer possible for individuals to practice "direct land application."
- Before 1800 city residents placed "night soil" in buckets along streets and workers emptied the waste into "honeywagon" tanks.
- The waste was transported to rural areas for disposal on farm land. The honeywagon system preserved the essential feature of land application of the waste.

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Toilets

- Until about 1850 even the members of Congress were required to go outside and walk down Capitol Hill to privy facilities.
- 1850-1900: The flush toilet came into general use in the U.S. during the last half of the nineteenth century.
- Introduction of the toilet coincided with ________ ______.

Night Soil vs. Sewers

- Dutch engineer Charles Liernur advocated dry disposal. He claimed underground sewers would be the source of _________ ______ giving rise to sickness and death.
- English engineer Baldwin Latham supported water carriage of excreta. Latham proceeded with the installation of a water carriage system for Croydon, where he was engineer of public works.
- The water carriage system led to an immediate decrease in the death rate in the cities that installed it.

Conversion of Storm Sewers to "Sanitary" Sewers

- Toilets were connected to existing storm sewers
- The storm drain systems discharged directly to streams, lakes, and estuaries without treatment
- Treatment of wastewater only became an issue after the self-purification capacity of the receiving waters was exceeded and __________ ____________ became intolerable

Wastewater into Streams: Enter Environmental Engineering!

- Drinking water treatment began to receive attention in the 1800s.
- London, and cities on the Great Lakes found themselves draining their raw sewage into the same body of water from which they took their drinking water.
  - Chicago solved this problem by reversing the flow of the Chicago river and sending its waste through a canal to the Illinois River to the Mississippi.
  - English engineers tackled the problem by developing treatment techniques for both wastewater and drinking water.

Evolution of Treatment Goals

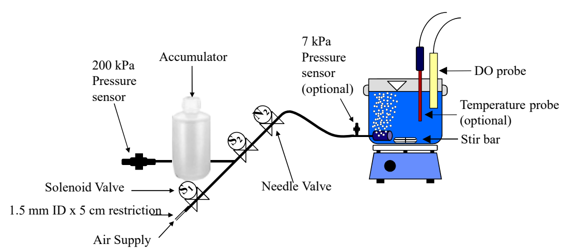
- Solids (sedimentation)
- BOD (activated sludge)
- Nitrification (convert ammonia to nitrate)
- Denitrification (convert nitrate to N_2)
- Phosphorus (get bacteria to take up phosphorus so phosphorus can be removed with the sludge)

Nutrient Removal Project

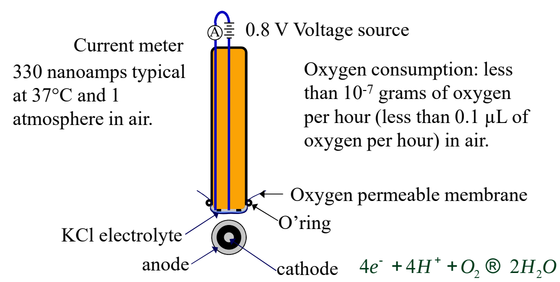
- The challenge: build an automated wastewater treatment plant that removes organic carbon from a synthetic feed
- Batch or continuous feed
- Maintain high cell concentrations using sedimentation
- We need to monitor oxygen levels
- We need air (oxygen)…

Gas Transfer and Dissolved Oxygen Probe

Spring 2015



Oxygen Probe



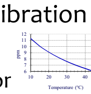
Dissolved Oxygen Probe: Theory

$$4e^- + 4H^+ + O_2 \rightarrow 2H_2O$$

- Applied 0.8 V reduces O_2 to H_2O at the cathode and keeps the O_2 concentration very low
- The cell is separated from solution by a gas permeable membrane that allows O_2 to pass through
- The rate at which oxygen diffuses through the gas permeable membrane is proportional to the difference in oxygen concentration across the membrane (proportional to the oxygen concentration in the solution) $J_m = -D_m \frac{\Delta C}{\Delta x}$
- Oxygen reduction produces a current that is measured by the meter

Dissolved Oxygen Probe: Calibration

- Single point (linear) calibration at saturation
  - Saturation concentration



$$C^* = P_{O_2} e^{\left(\frac{1727}{T} - 2.105\right)}$$

    - Temperature dependence
    - Atmospheric pressure dependence

$$k_{membrane}(T) = e^{0.05\left(T - T_{ref}\right)}$$

  - Membrane temperature effect
    - Diffusion through membrane is a function of temperature

$$k = \frac{C^*_{cal} k_{membrane}\left(T_{cal}\right)}{V^*_{cal}}$$

- Linear calibration coefficient
- Equation for calculating DO

$$C = \frac{kV}{e^{0.05\left(T - T_{ref}\right)}}$$

What Controls Oxygen Transfer?

- $C^* - C$ ________________
- ________________ $\hat{k}_{v,l}$
  - ________________
  - ________________
  - ________________
  - ________________

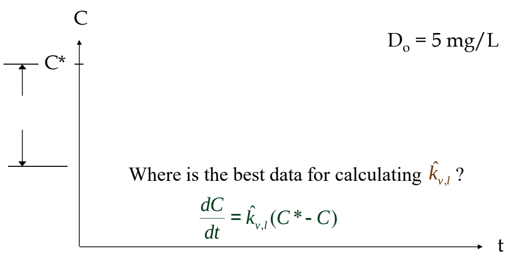
$$\frac{dC}{dt} = \hat{k}_{v,l}(C^* - C)$$

overall volumetric oxygen transfer coefficient

What is $\hat{k}_{v,l}$?

- Overall volumetric gas transfer coefficient
- *v* is for volumetric (it is based on the volume of the reactor rather than the more fundamental and illusive quantity of the interfacial area)
- *l* is for the liquid phase. The liquid phase transfer is the slow step in this process (gas phase transfer is very rapid) and thus liquid phase resistance completely dominates the gas transfer
- A first order reaction coefficient with units of 1/t

Aeration: Initial Oxygen Deficit, No BOD



C* = oxygen concentration in equilibrium with atmosphere

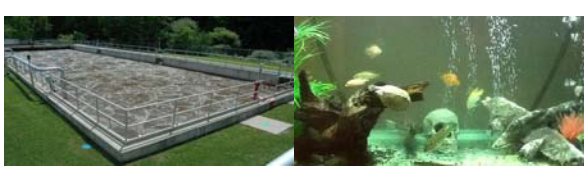
Measuring the Transfer Coefficient $\hat{k}_{v,l}$

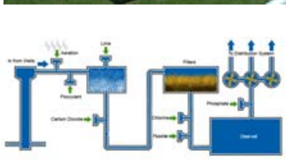
- Specific for a particular reactor design/configuration and for a specific flow rate
- We want to know how the transfer coefficient varies with flow rate (so we can estimate how much oxygen we are delivering)

$$\frac{dC}{dt} = \hat{k}_{v,l}(C^* - C) \xrightarrow{\text{integrate}} \ln\frac{C^* - C}{C^* - C_0} = -\hat{k}_{v,l}(t - t_0)$$

$\underline{y = mx}$

Aeration Processes





Aeration Methods

- Diffused Aeration Systems: (compressed air pumped into aeration tanks)
  - Porous diffusers
    - Ceramic
    - Plastic membranes
  - Non-porous diffusers (hole in a pipe)
- Mechanical Aeration Systems

Oxygen Transfer Efficiency (OTE)

- Percentage of the mass of oxygen transferred into the water divided by the mass of oxygen supplied to the water
- You will calculate OTE for your system
- OTE will be less under wastewater conditions
  - Lower oxygen solubility (salts, organic matter)
  - Lower surface tension

$$\frac{dC}{dt} = \hat{k}_{v,l}(C^* - C)$$

Oxygen Transfer Efficiency: O_2 dissolved / O_2 delivered

- How do we measure the rate that oxygen is dissolving?

$$\dot{n}_{aq\,O_2} = \frac{V}{MW_{O_2}}\frac{dC}{dt}$$

V is reactor volume

$$\frac{dC}{dt} = \hat{k}_{v,l}\left(C^* - C\right)$$

But *dC/dt* varies with oxygen deficit

Our goal is to measure this in lab

$$\dot{n}_{aq\,O_2} = \frac{V}{MW_{O_2}}\hat{k}_{v,l}\left(C^* - C\right)$$

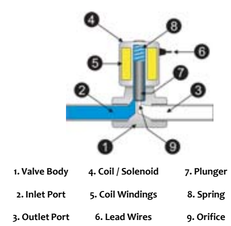
After we have measured the transfer coefficient we can easily calculate the oxygen transfer rate

Air Supply Design Questions

- How much oxygen will be required by the wastewater?
- How much air will need to be supplied?
- Number of diffusers
- Reactor configuration (shallow vs. deep)
- How will we supply the air?
  - Peristaltic pump
  - Laboratory compressed air (100+ kPa source) with air flow controller

Diffuser Air Supply Design

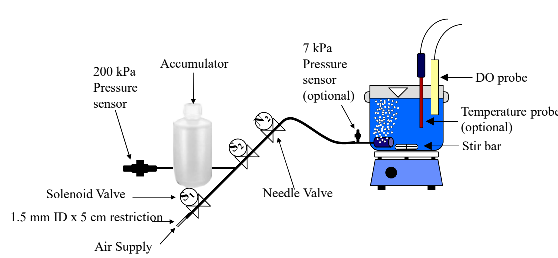
- If we use the laboratory air supply (100 kPa) for the NRP how could we regulate air flow?
- We have computer controlled solenoid valves.



Preparation for Lab

- Come ready to play
- Ask lots of questions!
- Make it your goal to understand as much of the system as you can!
- You will be assembling the airflow control hardware and creating the rules for the states to control the process

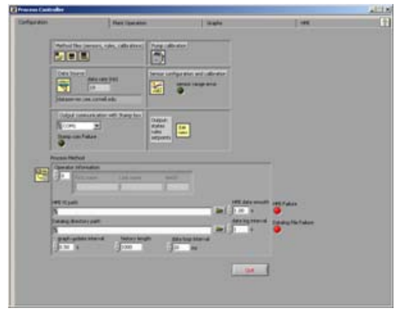
Lab Setup



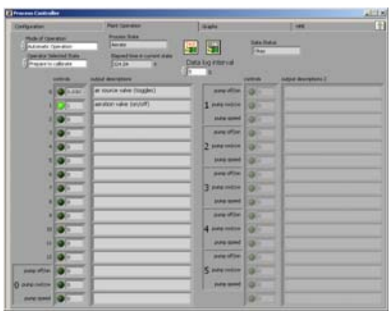
Process Controller

- The process controller software will be used to control the air flow rate
- The process controller software combines 3 elements:
  - sensors (inputs from the real world)
  - set points (inputs from the plant operator and calculated values based on sensors and other set points)
  - logic (rules that govern how the plant should operate given the sensor data and set points)
- A process controller method file containing the configuration necessary to control airflow
- Make it your goal to understand as much of the

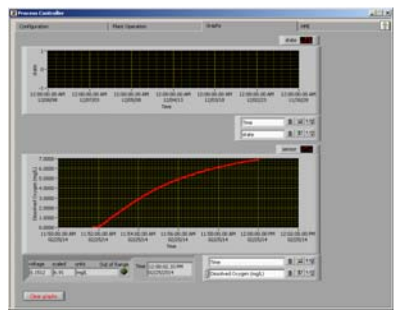
Process Controller



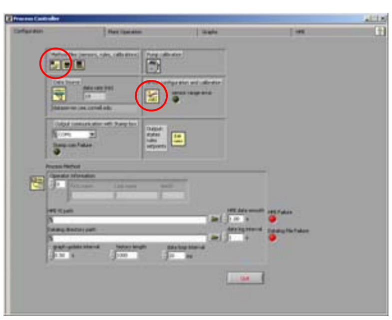
Process Controller



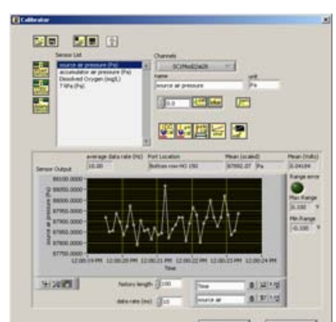
Process Controller



Process Controller



Process Controller



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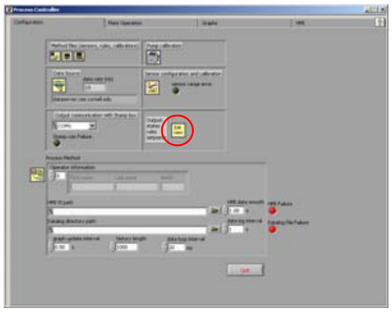

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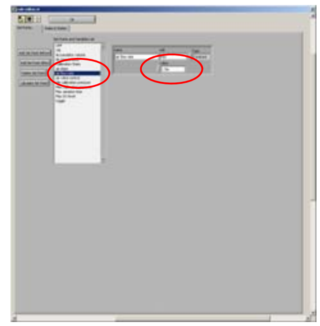
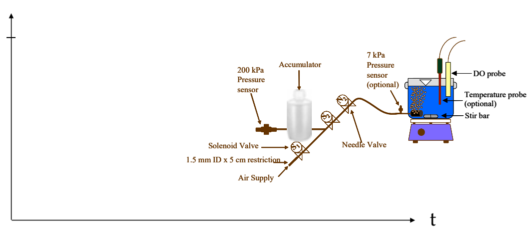


Calibration

- What happens if accumulator is empty, S2 is closed and S1 is opened?

P



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After Calibration

- What happens if accumulator is empty, S2 is closed and S1 is computer controlled to deliver a desired air flow in Mole/s?

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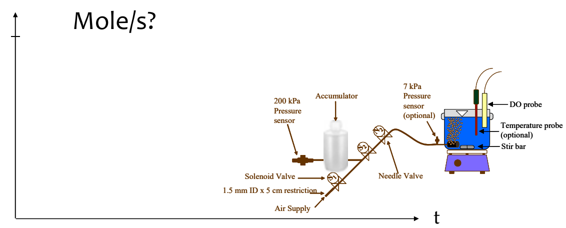

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Needle valve role?

- What happens to steady state pressure in accumulator as needle valve is gradually closed?

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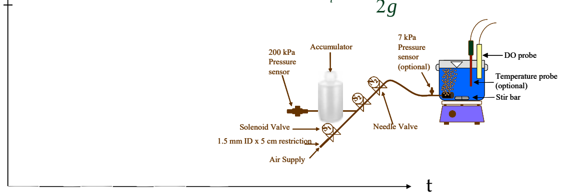
$h_l = K\frac{V^2}{2g}$ $\qquad Q \propto \sqrt{P}$



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Aeration Analysis

- Student data set…
- Large data set
- Plan how you will organize the analysis
  - How can you format the data so all of the data sets are addressed identically?
  - If you find the analysis repetitive, figure out how to program the computer to do the repetitive tasks
- Eliminate the creation of equations that need to be modified many times!
  - Indirect addresses
  - Lookup tables
- An empirical model for the oxygen transfer coefficient?

NRP Context… Can you control the oxygen concentration?

- Suppose that you knew the desired rate of oxygen transfer into the reactor
- How would you set the air flow rate?

$$\dot{n}_{aq\,o_2} = \frac{V}{MW_{O_2}} \hat{k}_{v,l} \left(C^* - C \right)$$

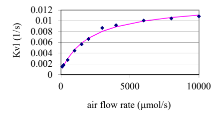
$\hat{k}_{v,l}$

$$\hat{k}_{v,l} = \frac{\dot{n}_{aq\,o_2} MW_{O_2}}{V \left(C^* - C \right)}$$

$\dot{n}_{gas\,o_2}$

A model for the oxygen transfer coefficient?

- Why are there diminishing returns at high flow rates?
- What will happen as the flow rate continues to increase?
- How would you draw a curve through the data?
- What type of function might produce this behavior?
- What is the transfer coefficient when the air flow rate is zero?



$$\hat{k}_{v,l} = \frac{\hat{k}_{v,l_{max}} \dot{n}_{air}}{\dot{n}_{air_{half}} + \dot{n}_{air}}$$

$$\dot{n}_{air} = \frac{\left(\hat{k}_{v,l} - \hat{k}_{v,l_{min}} \right) \dot{n}_{air_{half}}}{\hat{k}_{v,l_{max}} - \hat{k}_{v,l} + \hat{k}_{v,l_{min}}}$$

Data Hints

- What does our model describe?
  - Reaeration!
  - Therefore need to find sections of data containing reaeration!
  - Discard the rest
- Look for any errors in the data.
- Why might groups have different results?
- How might you modify the experimental protocol to collect a better set of data
- Check out how the graph contains the correct data range