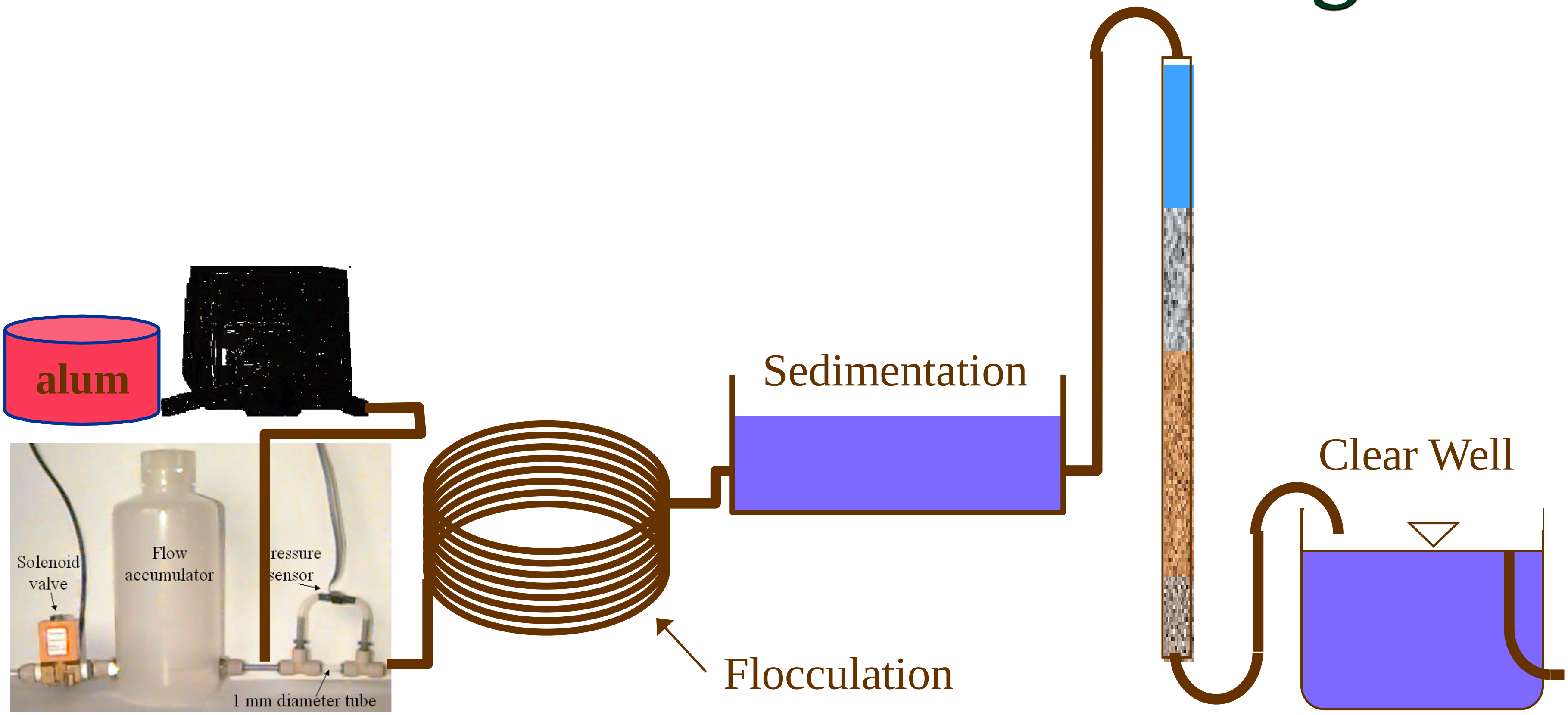
Water Treatment Plant Design



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Overview

- Safety
- Competition guidelines
- Trouble shooting guide
- Hydraulic challenges
- Surface tension
- Startup requirements
- Rapid Mix/Flocculation/Sedimentation
- Parting Pointers

Laboratory Safety

- Safety hazards
  - Electrical
  - Chemical
    - Aluminum Sulfate (alum)

MSDS

- Buddy System
- Don’t go into any other areas of the environmental laboratory
- Professional behavior
- PPE: Safety glasses, lab coat

Project Expectations

- Spend at least 4 hours per week working on WTP outside of class
- Keep an Excel time sheet (time in, time out, task, and weekly totals) for each of you (email weekly on Thursday to Jeff)
- Work together as a team and divide up tasks
- Spend time teaching each other what you are learning
- Professional Play! (Have fun!)

Team Work

- Think efficiency
- You can't all work on the same thing!
  - Compare your team work to soccer players
  - Don't bunch up!
  - Give each other permission to experiment with the plant
- Make a project schedule

Water Treatment Plant Goals

- Best value (meets EPA turbidity standard with lowest annual cost of production for NYC)
- Longest continuous operation
- Best plant control logic
- Best plant design
- Best maintenance plan for cleaning sedimentation tank and flocculation tank
- Documentation of experimentation, data analysis, and appropriate plant modifications

EPA Turbidity Standards

- As of January 1, 2002, turbidity may never exceed 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month.
- Our requirement will be that the turbidity be less than or equal to 0.3 NTU at all times
- The [(flow rate at the time of a turbidity violation) x (12 hours)] will be deducted as a penalty from the total plant production
  - Note that if the TAs collect more than 2 samples per day it will be possible for the penalties to exceed the production!
- TAs will measure the flow rates and the turbidity several times per day and email results to the class

Economics

- Capital costs
  - Cost of building the various components
  - building
  - Controls and sensors
- Operation and Maintenance costs (O&M)
  - Chemicals (alum)
  - Electricity
  - Labor
- Both capital and O&M costs contribute to the cost of the water produced
- We will only include the capital costs for this competition

Competition Economics

- We will only include the costs for the processes that you can control
- The costs will be scaled as if your plant were full scale
- Otherwise the computer, data acquisition system, and control hardware would completely dominate the cost!
- The clear well and the flow accumulator will not be included in the economics

Capital Cost Estimates Used for the Competition

Item	cost		unit
filters	8000	$\$/m^2$	surface area of filter
garnet	90	$\$/m^3$	volume of garnet
sand	20	$\$/m^3$	volume of sand
anthracite	30	$\$/m^3$	volume of anthracite
rapid mix tank	5000	$\$/m^3$	volume of rapid mix tank
flocculation tank	2500	$\$/m^3$	volume of flocculation tank
sedimentation tank	2000	$\$/m^3$	volume of sedimentation
lamella	20	$\$/m^2$	total surface area of lamella

Calculating the cost of water from your plant if applied to NYC

- Calculate the cost of your plant
- Assign cost for 1 week of operation assuming 25 year life (1/1300th of total capital cost)
- Calculate the amount of water produced in the week of the competition
- Subtract any water that was produced within 12 hours of a turbidity standard violation
- Calculate the cost per m^3 of water produced
- Calculate the annual cost for using your process to provide 60 m^3/s to NYC

When it doesn't work!

- You are creating a complex system
- Any component that fails can lead to failure in the system
- How do you identify the source of a problem?
- Attempt to identify the events that could cause a failure in advance

Scientific Method of Troubleshooting

- The Scientific method:
  - Clearly identify the problem
  - Create hypotheses
  - Design experiments to test the hypotheses
  - Draw conclusions based on the data
- How can you choose which components to test first?
  - Intuition?
  - Ask which component could cause the observed symptoms
  - Requires an understanding of how the system works!

Modular Approach

- How can you build a complex system with the greatest probability of ultimate success?
- Break a system down into its components and test individual pieces
- Only add components to the system after the components have been tested
- Begin with the system as simple as possible
  - What would the simplest operating rules be?
  - Add unit processes one by one

State Machines

- What are the potential states for your water filtration plant?
  - Off
  - Down flow
  - Backwash
  - Media settle
  - Filter to Waste

Plant State Logic

- Assume your water treatment plant is currently backwashing.
- Under what conditions will the plant switch to a different state?
  - Time greater than max set point
  - Time greater than min set point and Above filter turbidity less than set point
  - Clear well empty

Output Device Control

- Some of the controls are either on or off depending on the state
  - Centrifugal backwash pump
  - Filter to waste valve
- Some of the controls have variable settings
  - Alum pump rpm
  - Flow control valve

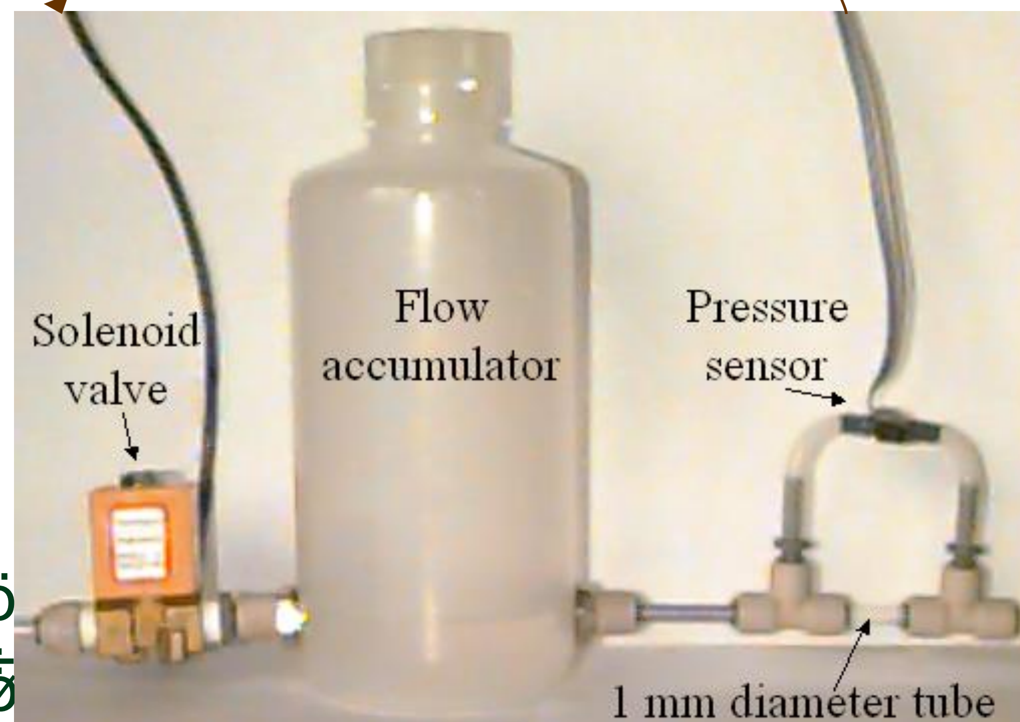
Alum pump rpm

- How might a plant operator want to control the alum pump?
  - Pump rpm
  - Alum stock flow rate
  - Alum mass rate
  - Alum concentration after mixing
  - Fully automatic based on raw water turbidity
- What inputs are required?

Flow Control Valve

- How should the solenoid valve be controlled?
- What role does the flow accumulator play?
- What will happen to the flow rate if the valve is opened for a short period of time?

Closed loop control logic



$$u(t) = K_c \left(\overset{\text{P}}{e} + \overset{\text{I}}{\frac{1}{T_I} \sum e \cdot \Delta t} + \overset{\text{D}}{T_D \frac{\Delta e}{\Delta t}} \right)$$

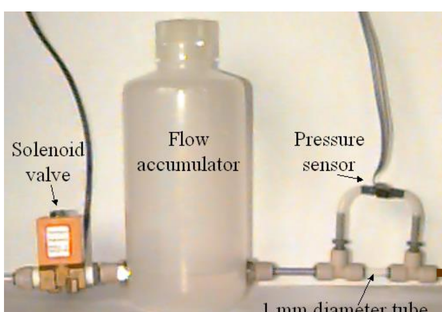
Hydraulic Challenges

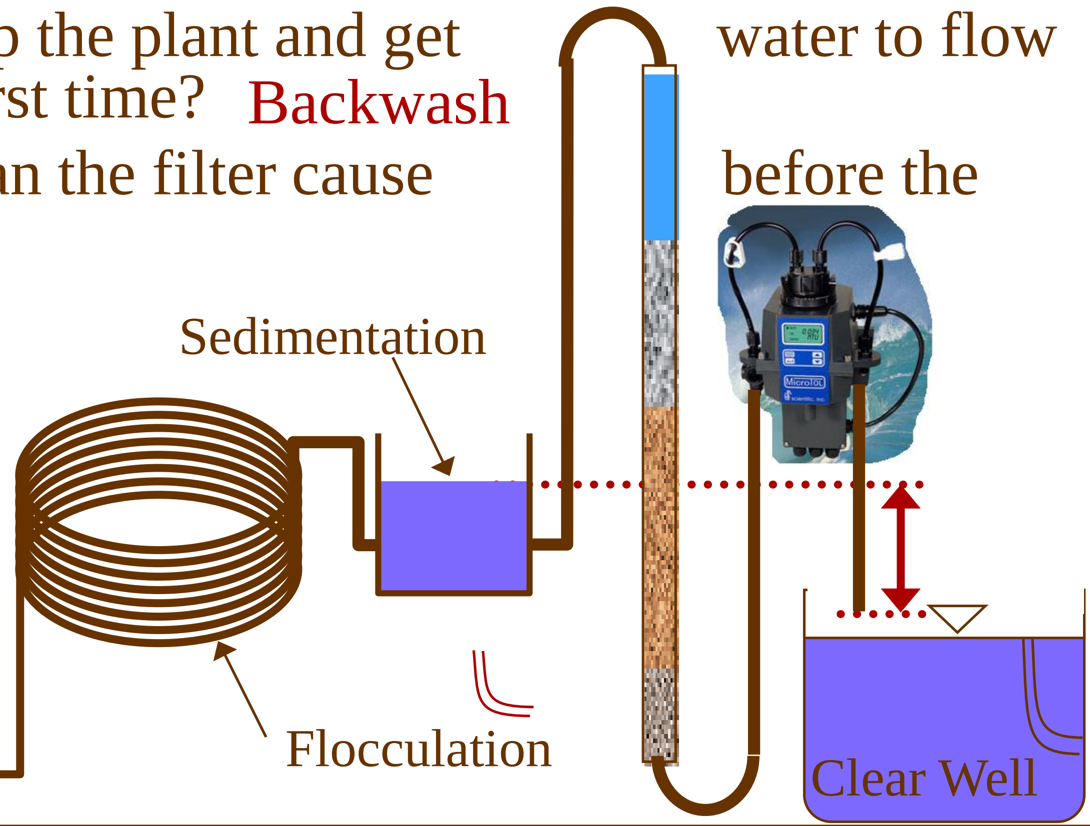
(getting the water to go where you want it to go)

- Leaks
  - Connections not sufficiently tight
  - Improvised connections lacking a good seal
- Overflows
  - Caused by water not going where you thought it was going
  - Open channel flows (air and water) – coming up
- Excessive head loss
  - Tubing size too small
  - Filter clogging

Simplified WTP Schematic

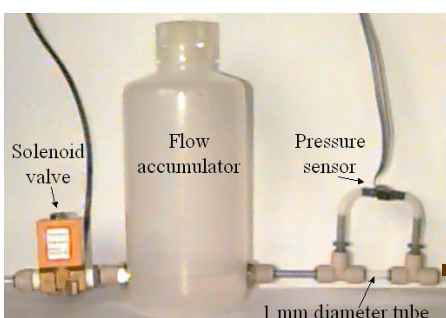
- Can the flow accumulator be on the bench top? Yes
- What controls the sedimentation tank water level? Overflow weir
- Why does the water flow through the filter? Elevation difference
- How would you start up the plant and get water to flow through the filter the first time? Backwash
- How much head loss can the filter cause before the system fails?

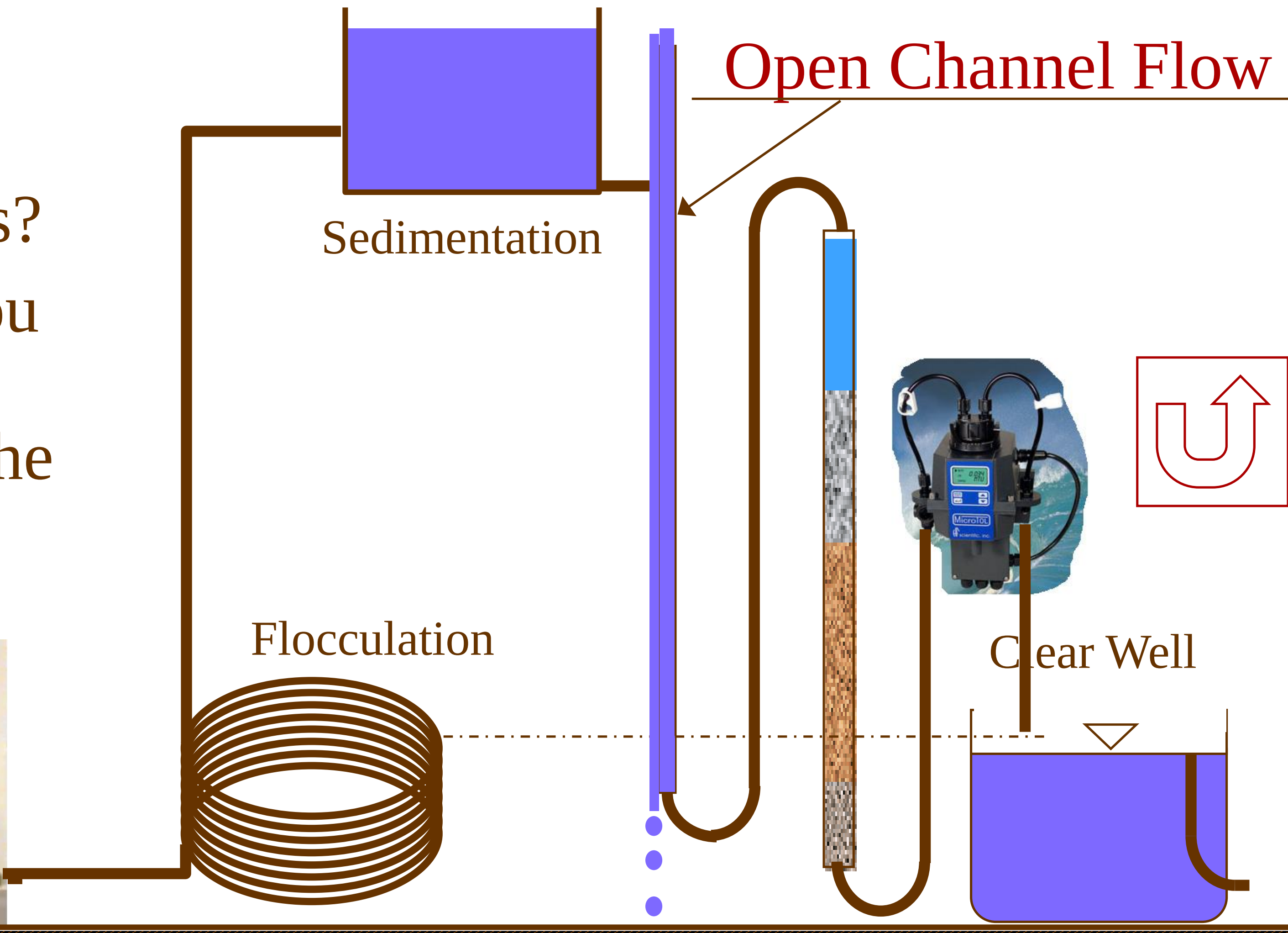




Improved WTP

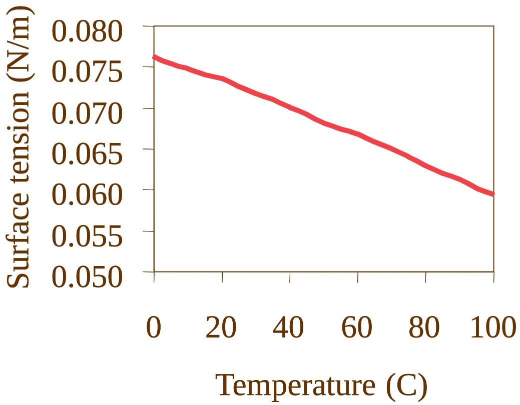
- Why is this better?
- Max head loss?
- How could you measure head loss through the filter?





Relative Strength of Forces

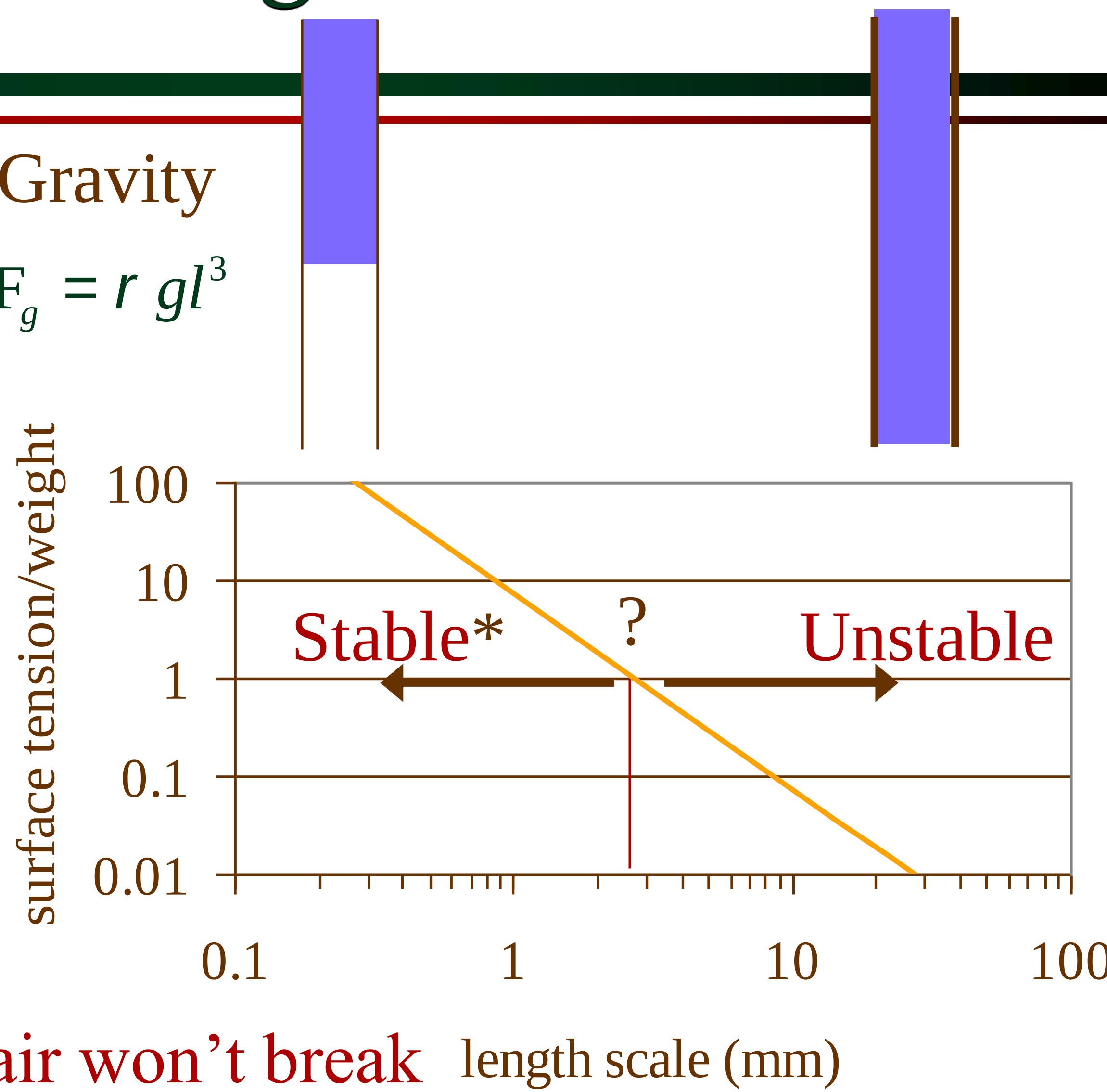
Surface tension



$$F_s = \sigma l$$

Gravity

$$F_g = \rho g l^3$$



* water column over air won't break

Open Channel Flows: Water and Air

- All overflows tubes are open channel flow
- Minimum <u>inside</u> diameter for sink drain is 6.35 mm (¼”)
- Minimum <u>inside</u> diameter for line where water level moves up and down based on filter head loss is 9.5 mm (3/8”)
- What happens if the tubing isn’t large enough for open channel flow?

Leak and Overflow Prevention

- Clear well overflow line must be horizontal or sloping down (can’t go up and down)
- What happens if head loss through the filter increases too much?
- Check each tank or tube with an opening to the atmosphere and ask:
  - What could cause an overflow at this location?
  - How could we design the system to reduce risk of failure
- Turn off the manual supply valve when you aren’t using the plant
- Make sure that all solenoid valves are off when the plant isn’t being used.

Plant Layout

- Design a plant layout that is easy to follow
- Tubing lengths can be changed so you can place your devices anywhere you want them
- Beware of large diameter horizontal tubes containing particles
  - Why?

WTP

Startup Requirements

- Stamp module must be on the computer side of the bench divider
- Must prove that excessive head loss will cause the filter to backwash before causing a flood!
- Must show that backwash won't empty clear well
- Must show that the plant switches between states correctly

Pointers

- Pressure sensors must be kept dry (they can fail if one drop of water soaks into the terminals)
- Use manual valves to make it easy to drain tanks
- Make sure you are using the most recent method file in your folder!
- Save a new version of the method file every time you make changes
- Label all processes
- Label the alum stock bottle
- Label all containers containing fluids

Operating Criteria

- Initial down flow rate of 5 m/h (40 ml/min)
  - If you increase the down flow rate make absolutely sure that the plant doesn't overflow
- Use your water treatment plant design homework to calculate the best stock concentration of alum
  - The best stock concentration might change if you significantly change the plant flow rate
- Plan to have someone check on the plant at least once per day (alum stock!)

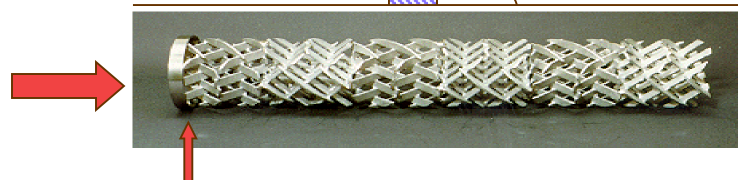
Rapid Mixing

Goal?

- *Hydraulic Jump*: Hydraulic Jump creates turbulence and thus help better mixing.

Poor

- *In-line flash mixing*



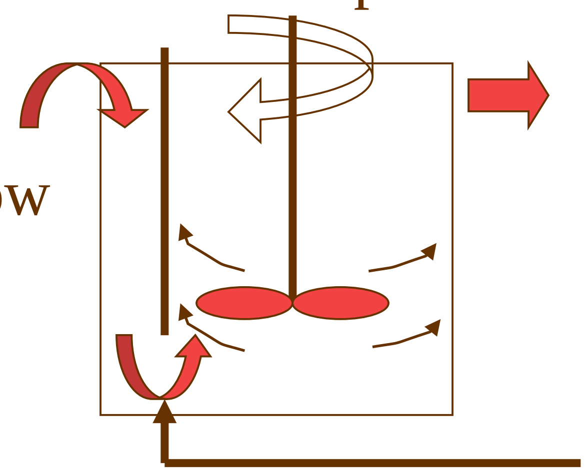
Coagulant

Excellent

- *Mechanical mixing*

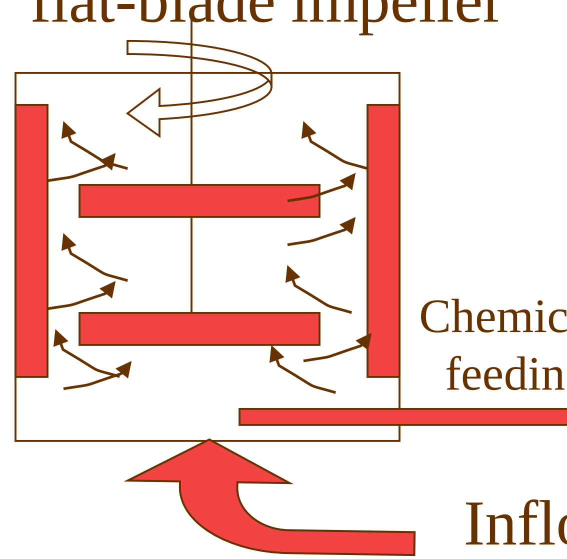
Back mix impeller

Inflow



Chemical feeding

flat-blade impeller



Chemical feeding

Inflow

Flocculation Design

- Goal: produce large flocs from tiny particles
- Collision Mechanism:
  - SHEAR
- We are doing research to find
  - Shear that will cause floc to break apart (floc strength)
  - $G\theta$ necessary to produce big floc (will dictate length of tube flocculator)
- Transfer into sedimentation tank must be done without increasing the shear
- How short can you make this?

Given $\bar{G}\theta$, Q and d, Find Floc Tube Length

$$\bar{G} = \frac{64Q}{3\pi d^3}$$

True for laminar flow

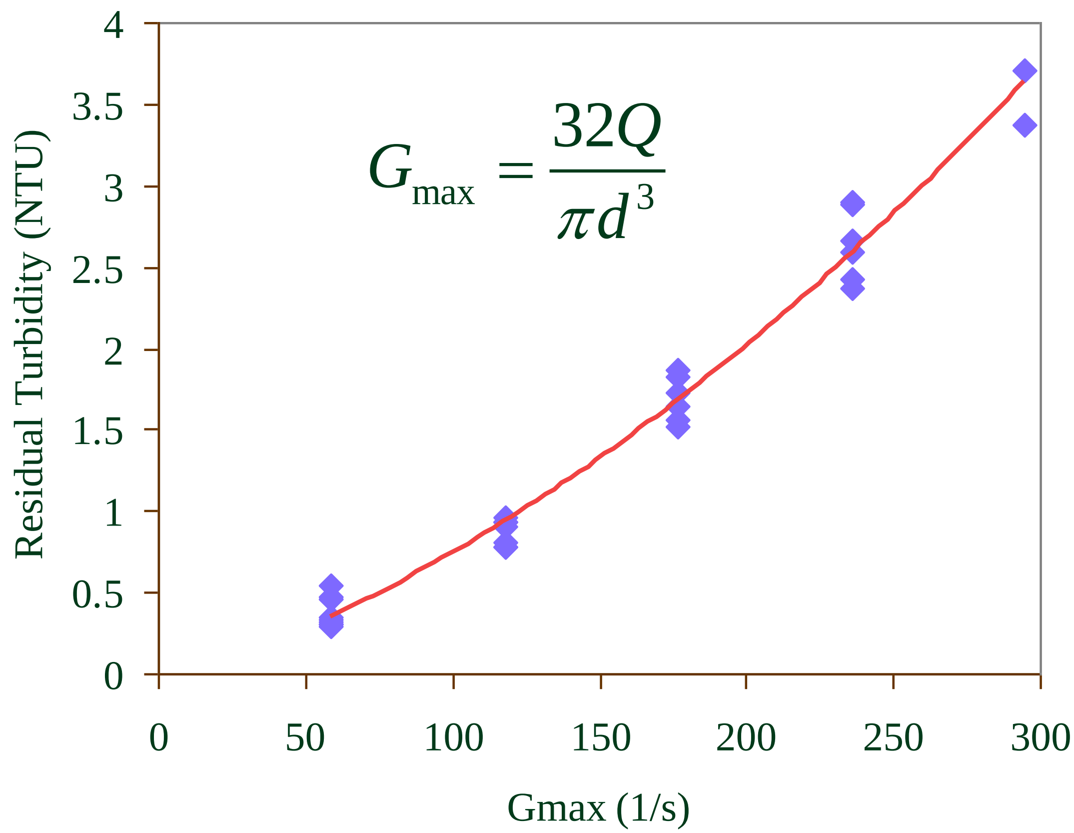
$$\theta = \frac{\forall}{Q} = \frac{\frac{\pi d^2}{4}L}{Q} = \frac{\pi d^2 L}{4Q}$$

$$\bar{G}\theta = \frac{\pi d^2 L}{4Q} \cdot \frac{64Q}{3\pi d^3} = \frac{16L}{3\pi d}$$

$$L = \frac{3\pi d\bar{G}\theta}{16}$$

Turbidity after Sedimentation Increases with Maximum Shear

- As shear increases floc size decreases
- Small floc settle more slowly
- It is possible that some very small colloids are produced when large floc breakup
- Net result: higher shear causes higher turbidity after sedimentation



Sedimentation Tank

- Up flow through a sludge blanket at 50 m/day can create excellent quality water
- Additional flocculation occurs in the sludge blanket
- Lamella might increase particle capture
- Lamella spacing must be larger than the flocs you are trying to capture
- You can save money by making this as small as possible

How will your Team Win?

- Produce the most clean water
- Keep costs down
- Efficient use of flocculation/sedimentation tanks
- Judicious use of filter to waste
- Only backwash when needed
- Well designed filter media (donated by US Filter)
- Document your design process
- Get your plant running ASAP so you can improve it before the competition begins.

Good Engineering?

- How would you approach this task as a Cornell engineer in a way that is different then how you would approach it in elementary school?
- How do you learn about the physical world?

Competition Submission

- Submit 5 copies by 5 pm on Thursday (May 5).
- Executive Summary
  - A one page cover letter to the judges where you introduce your design firm, identify the members of your design team, and describe the important features of your water treatment plant.
- Final plant schematic
  - all valves, sensors, tanks, and pumps with correct relative elevations. Clearly show the elevation of the laboratory bench top.
- Description of your design and your design process
  - How did you size the unit processes in your plant? SHOW CALCULATIONS
  - How did you test the plant?
  - How did you use data that you acquired to modify the design?
  - What are the special features of your plant that make it the best?

Parting Pointers

- Hydraulics: water flows from higher potential energy to lower potential energy
- Leaks: fix them right away, clean up all spills immediately, keep bench dry, sensors and controls die when wet!
- Save incremental versions of process control method whenever you make changes