Jar Testing Theory and Practical Applications

Parts 1 & II

Practical applications for water plant operators

Nick Pizzi

nick@aqsrv.com

OTCO Water Workshop - April 2, 2019

Topics

- We will cover these topics:
  - Rules for full-scale to bench-scale calculations used in jar testing
    - Jar test theory
    - Create a meaningful and detailed plant schematic
    - Show how to use G values to set mixer speeds on the jar tester
    - Learn how to calculate realistic settling times for the jars
    - How to make some of the stock solutions for the tests
    - Learn how to calculate your "enhanced coagulation endpoint"
- Throughout, we will Emphasize the Operational Perspective
  - Learn to Understand What the Engineers are Telling Us
  - Learn How to Prepare for Jar Tests When the Pressure is On

References

- "AWWA Manual M37", 3rd Edition, AWWA 2011
- "Pretreatment Field Guide", Pizzi, Nicholas G., AWWA 2011
- USEPA Rules: the IESWTR requirements for Turbidity and TOC removal

Why run a jar test?

- Two chemical suppliers come in with their products, and each claim that their coagulant is better for your conditions. How do you choose?
- Your bid documents include statements that the bidder submit a sample of their activated carbon product to prove their claims. What do you do?
- You think that $KMnO_4$ might be useful – but you're not sure. How will you know?

Operator Involvement

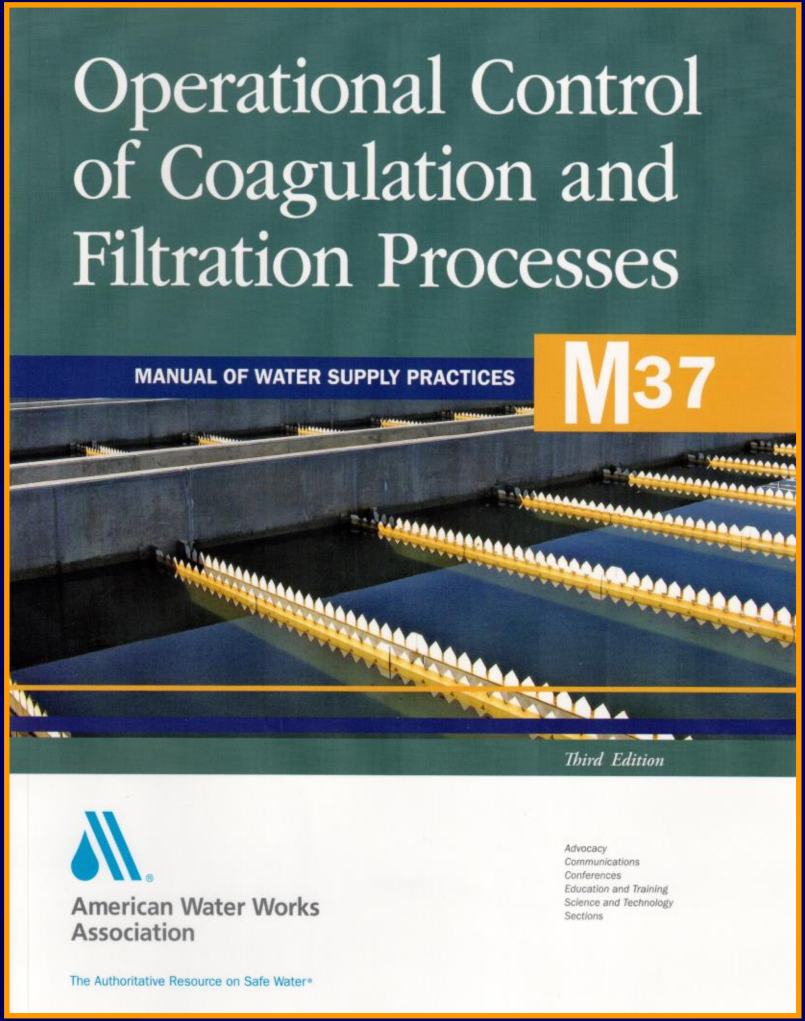
- In spite of the valuable information that jar tests can provide to operators, they often shun this tool because of perceived difficulty
- Jar tests seem cumbersome and time-consuming especially at a time of plant upset
- In many WTPs, its just the plant manager or lab analyst that knows how to run a jar test
  - The operator on shift is likely the one who needs to know how
- For our session today, we will create a sample operator friendly jar test protocol

JAR TEST RULES FOUND IN AWWA'S M37

Jar Test Theory

"The jar test is recognized throughout the water industry as a valuable tool for realistically simulating coagulation, flocculation, and sedimentation at a full-scale plant."

- Manual M37, page 17



A MORE MEANINGFUL PLANT SCHEMATIC

Lake County, OH Aquarius WTP

- We’ll use this plant as our example for how we might set up a protocol
- We need to know about the pre-treatment processes that are employed at this plant
- We need to know how to translate the full-scale pre-treatment processes down to the jar-scale in order to make the protocol useful
- To do this, let’s first examine the plant’s configuration and capabilities

Aquarius WTP

- This is a conventional WTP using Lake Erie as its source
  - Nominally rated at 20 mgd
  - Can filter, disinfect, and pump in excess of 30 mgd
- Uses the following unit processes:
  - rapid mixers, flocculators, sedimentation basins, granular media filters, and disinfection (hypo)
- Serves communities in western Lake County
  - Willoughby, Eastlake, Willoughby Hills, Wickliffe, Willowick, Lakeline

Raw Water Station Permanganate System

Day tank and feed pumps

Speed control and chart

- 300 gallon capacity. Solution is 0.25 pounds per gallon $KMnO_4$
- Normal dose is about 0.3 mg/L - this must be accounted for in the jar test if it pertains to your plant – depends on the source water sample location

Two Treatment Schemes at this WTP

Parallel Flow

- Raw water comes into the plant and is split into two equal streams that flow into each of the rapid mixers where coagulant is added, and any other chemicals that are needed.
- The mixed water flows into the flocculation section of the plant. Each of the six flocculators has motor-controlled inlet and outlet gates so they can be put online or taken out of service as needed.
- Water flows from the flocculators into the distribution channel and can be directed to any or all of the sedimentation basins for settling.
- Water flows from the sedimentation basins through the settled water flume where it can be disinfected and fluoridated on its way to the filters.

Series Flow

- Raw water comes into the west rapid mixer where coagulant is added and mixed in, and then it is sent on to the three west flocculators, and then into the two west sedimentation basins.
- Settled water from the basins travels north through the series flow channel and into the east rapid mixer. Here, the operator can add more coagulant, a polymer, hypochlorite, and/or activated carbon before the water flows into the east three flocculators and the two east sedimentation basins.
- Water flows from the sedimentation basins through the settled water flume where it can be disinfected and fluoridated on its way to the filters.

Rapid Mix

- 2 units each @ 676 cubic feet or 5,056.5 gallons
- Detention time
  - At 10 mgd is 43.6 sec
  - At 20 mgd is 21.8 sec
- One motor with one shaft and two impellers on the shaft
  - 4 redwood baffles

Rapid Mix

- Coagulant added here
- Mixer motor assembly provides G value of 700 sec^{-1}
  - Should always be operated
- Chlorine and caustic can be added also
- They add enough coagulant to remove 25% of the incoming TOC, and also to remove turbidity

Coagulant Feeders

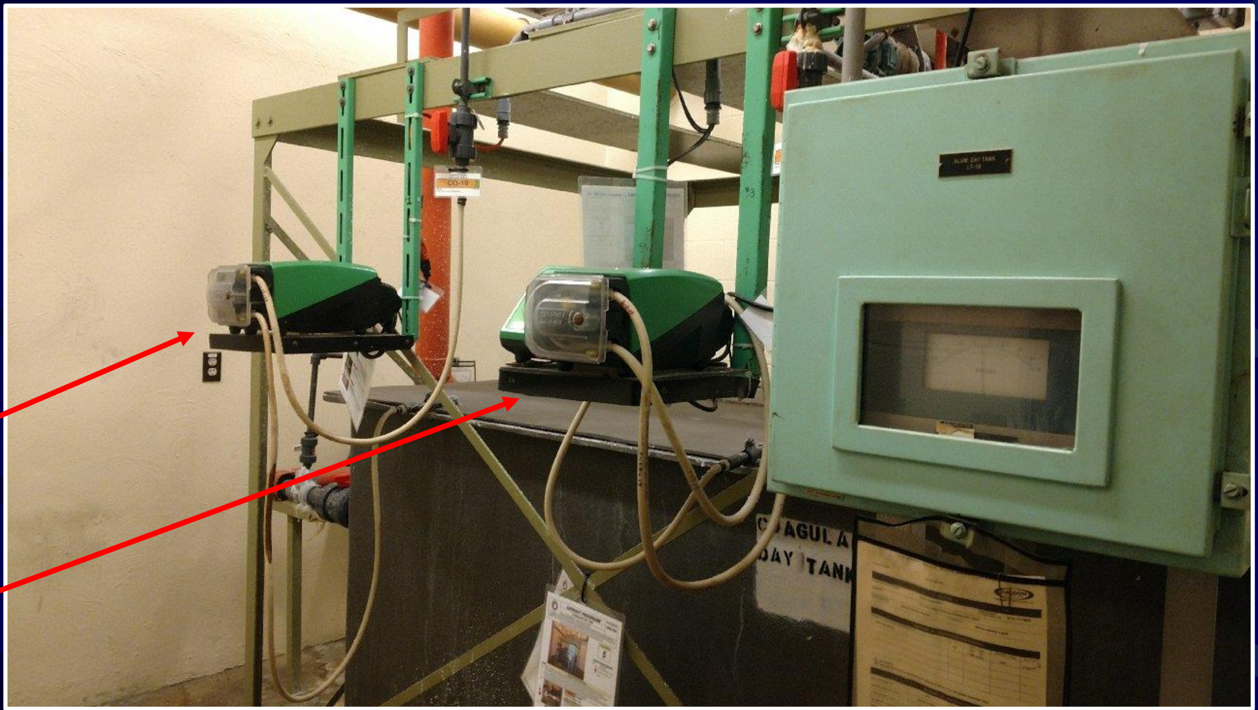
There are three total:

- Two of them are peristaltic
- Old is an old style diaphragm type

#1

#3

#2 (not shown)



Flocculation

- 6 units each @ 14,080 cubic feet, or 105,318 gallons
- Detention time with all in service
  - @ 10 mgd = 90 mins
  - @ 20 mgd = 45 mins
- Each flocculator has one motor and shaft
  - 4 compartments
  - 4, 3, 3, and 2 paddles
  - Nominal G values are 70, 50, 50, and 20 sec^{-1}

Aquarius Flocculation

Flocculators	
Number of units	6, tapered flocculation
Make	Envirex
Dimensions	16’ X 55’ X 16’ water depth
Volume	14,080 ft^3, 105,318 gallons (each)
Stages	4
G Values	70, 50, 50, and 20 sec^{-1}
Detention time at 10 MGD	(6) 14,080 ft^3/930 ft^3/min = 90 min (all in service)
Detention Time at 20 MGD	(6) 14,080 ft^3/1,860 ft^3/min = 45 min (all in service
Diameter of paddle travel	12 foot, and 3.14 X 12’ = 37.68 perimeter
Speed range	1.22 to 3.65 rpm
Final paddle tip speed range	0.76 to 2.3 fps

Flocculator tip speed

The flocculator drive mechanisms are equipped with a hand wheel which can be rotated to increase or decrease shaft speed

The circle that the tip of the paddle travels has a perimeter of 37.68 feet

They view the travel of the paddle in the water, and use a watch to measure the amount of time it takes for 1 complete revolution

They divide 37.68 feet by the time in seconds for one revolution

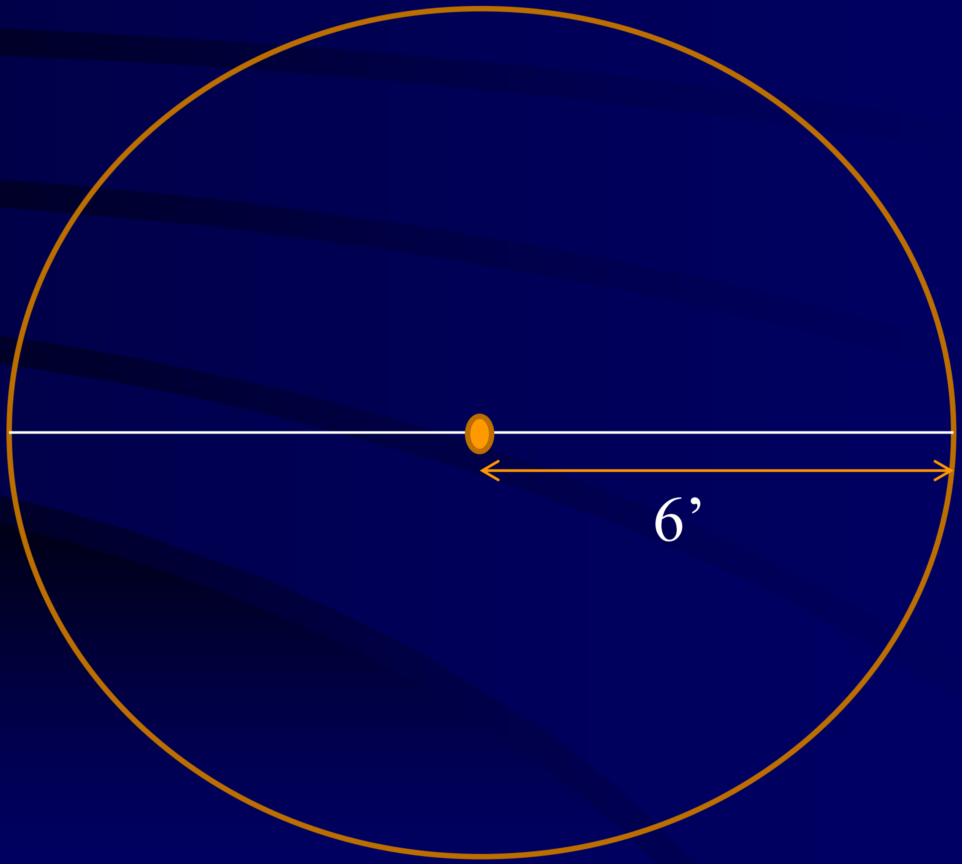
This gives them the tip speed in fps

Tip speed calculation

- 1 rotation of a paddle travels 37.68 feet
  - Step 1 – determine the desired tip speed
  - Step 2 – measure the actual tip speed
    - Step 2a – measure the time it takes to travel around once
    - Step 2b – divide 37.68 by the number of seconds you measured
  - Step 5 – adjust speed as necessary
- Example: say they want 1 fps. They measure 1 rotation at 40 seconds. (37.68 ft/rotation)/40 seconds/rotation) = 0.94 fps.
  - They would increase speed at the motor assembly

Flocculator travel distance

Perimeter of a circle cut out by the travel of the paddle is = to 3.14 X Diameter



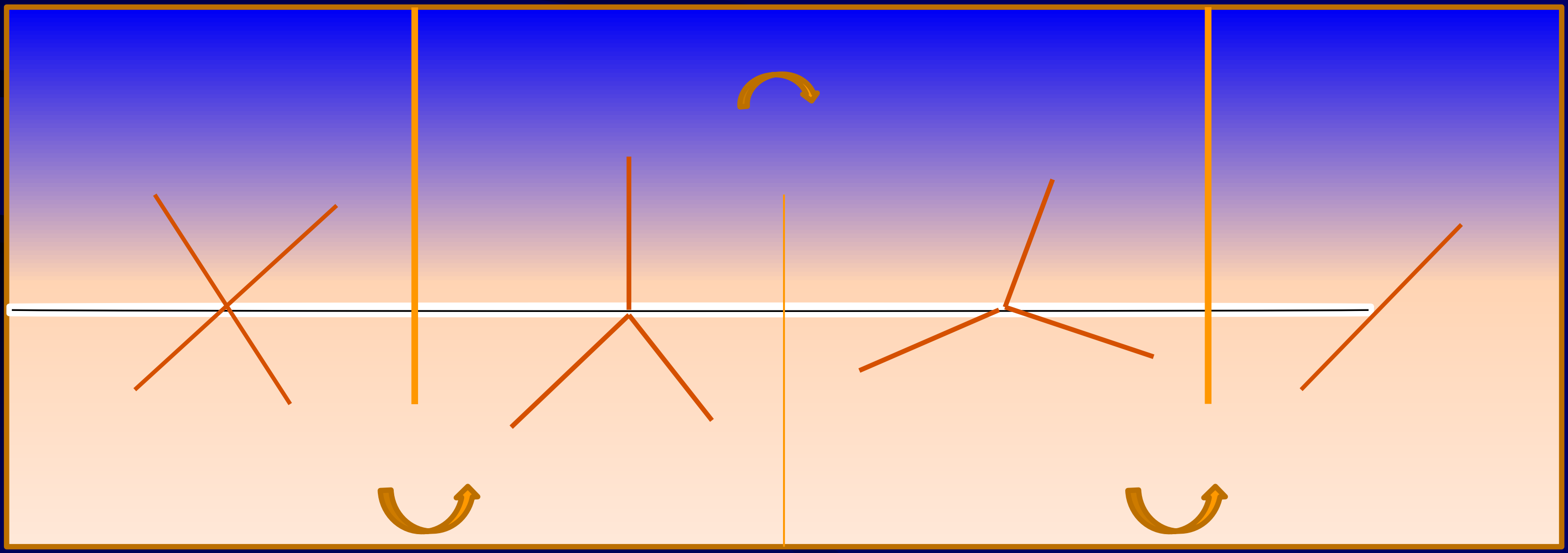
Therefore, 1 rotation is 3.14 X 12’ = 37.68 feet

Measure the time it takes to make one revolution, then divide that time into 37.68

That yields the tip speed in fps

Aquarius Flocculators

- The flocculators at Aquarius are compartmentalized, and have paddle mixers



Sedimentation

4 units each @ 112,955 cubic feet, or 845,000 gallons

Detention time

@ 10 mgd = 8 hours

@ 20 mgd = 4 hours

V notch weirs

8 weirs per basin, double sided, 17.5 feet in length

total weir length of (17.5' X 2 sides X 8 weirs X 4 basins) = 1,120 feet

Weir Overflow rate

Design weir overflow rate is 12.4 gpm/ft, or 17,857 gpd/ft

Example: calculate the WOR if three basins are in service and the WTP is treating 12.4 mgd

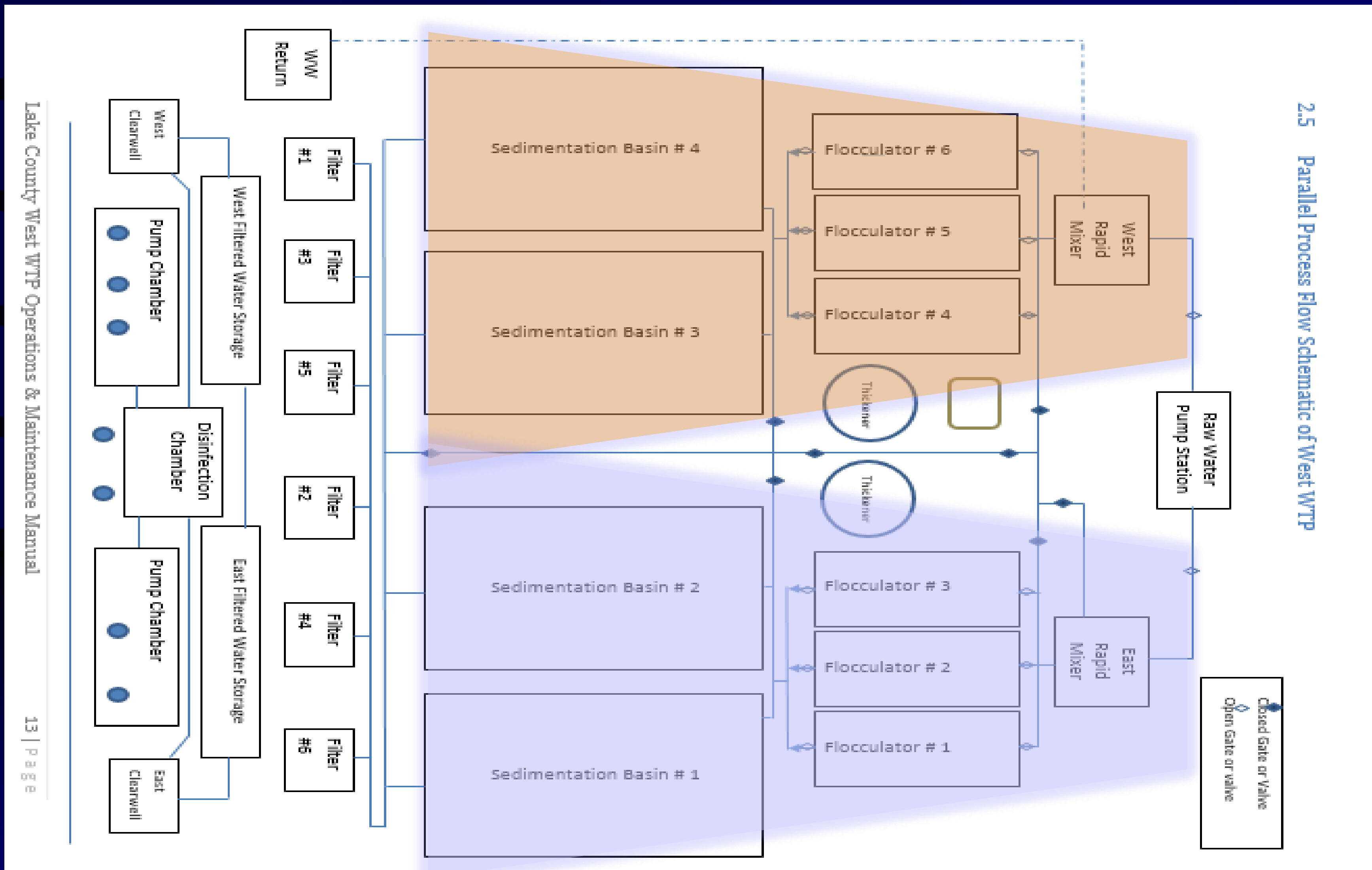
12,400,000 gpd ÷ 1,440 min/Day = 8,611 gpm

(8,611 gpm) / (3 basins x 17.5' x 2 sides x 8 weirs) = 10.25 gpm/ft

Aquarius Sedimentation

Sedimentation Basins	
Number of Units	4
Dimensions	41’ X 190’ X 14.5’ water depth (each)
Area of basins	7,790 ft^2 each
Basin Depth	14.5’
Volume of basin	112,955 ft^3 each (845,000 gals)
Design settling velocity	0.45 gpm/ ft^2 or 1.81 cm/min
Detention time at 20 MGD	4 hours with all in service
Weirs	8 double-sided weirs per basin – 1,120’ total
Weir overflow rate 10 MGD	10,000,000 gal/day/(17.5’ X 2 sides X 8 weirs)(4 basins) = 8,928 gal/day/ft
Weir overflow rate 20 MGD	20,000,000 gal/day/(17.5’ X 2 sides X 8 weirs)(4 basins)= 17,857 gal/day/ft
Surface Overflow Rate (SOR) at 20 MGD	20,000,000 gal/Day / (4 basins)(7,790 ft^2 each) = 642 gpd/ ft^2 or 0.445 gpm/ft^2

Process Schematic of WTP



Lake County, OH Aquarius WTP Process Schematic

(approximations for Aquarius jar test – WTP in parallel)

Each Sedimentation Basin is Approximately 41' wide with a length of 190'. Surface area of each basin is 7,790 ft^2.

Zone 2 ,3, 4 and 5 flocculation is baffled. Each flocculator is approximately 16'w.d. X 16' wide X 55' = 14,080 cubic feet, or 105,318 gallons each. So each zone is ¼ that, or 26,330 gals. Zones have tapered flocculation accomplished by 4,3, 3, and 2 paddles respectively.

THEORY OF HOW THE CALCULATIONS WORK

Jar Test Theory

In the conventional WTP, we have three steps in series:

1. Step 1 - Water flows into a rapid mixer
    - Coagulant is added to start the coagulation process
    - Important to know: detention time, coagulant dose, mixing energies (G), other chemicals being used
2. Step 2 - Water flows to flocculator
    - Gentle mixing to grow larger flocs
    - Important to know: detention time in each compartment, mixing energies (G) of each compartment
3. Step 3 - Water flow to settling basin
    - Water slows down and particles settle out
    - Important to know: surface overflow rate (SOR)

…. we do all three steps in the same jar

Timing/Mixing Speed Rules for Jar Tests

Steps 1 & 2 - Mixing and Floc steps

- Full-scale Detention Times are used exactly "as is" for the jar-scale
- Full-scale mixing energy (G value) must be "scaled-down" to determine paddle speeds at jar-scale
- Where full-scale rapid mixing G value is higher than you can achieve on your jar tester, use "G X T" to compensate

Step 3 - Settling step

- Full-scale Detention Time is meaningless – **do not use it**
- Full-scale SOR determines the jar-scale settling time
- Convert the SOR gpm/sq ft to the settling velocity in cm/min
- Divide the distance of the sample port in the jar (in cm) by the settling velocity to get sample time

SOR and Jar settling time

- The mistake most operators make is to settle the jars too long before sampling
  - Think of your SOR as an upward force in your sedimentation basins that impedes the ability of particles to settle by way of gravity
  - The higher the SOR, the more particles will carry over to filtration
  - If you correlate SOR to the time and distance a particle has to settle in the jar, you will know when to take a sample

How do we do this?

Typical 2-Liter Square "Gator" Jar

When you fill the jar up to the 2-Liter mark, the top of the water level is about 10 centimeters from the sample port

So any particles that settle below the 10 cm mark won't be captured when you take a sample

Any particles above the sample port will be captured in your sample when you take it. Obviously, the longer you wait to sample, the more particles you will miss.

If you convert your SOR to a speed or velocity in centimeters/minute, you'll know how long to wait until you take the sample.

The key step!

Example:

- If the SOR for your plant is say 0.45 gpm/ft^2, you convert that to cm/min this way:
  ($0.45\ gpm/ft^2$) x (1 ft3/7.48 gal) x (30.48 cm/ft) = 1.83 cm/min

Finally – divide the 10 cm by the 1.83 cm/min = 5.5 mins settle time

Shortcut: The number 4.07 multiplied by your SOR will = cm/min

Where does the 4.07 come from?

SOR Units	Multiply by	Settling Velocity
mgd/ft^2	2,830	cm/min
gpm/ft^2	4.07	cm/min
gpm/ft^2	2.44	m/hr
gpm/ft^2	1.60	in/min

Table in AWWA Manual M37, page 20

USING G VALUES

How to use G curve chart

Chart Y axis – G value full scale

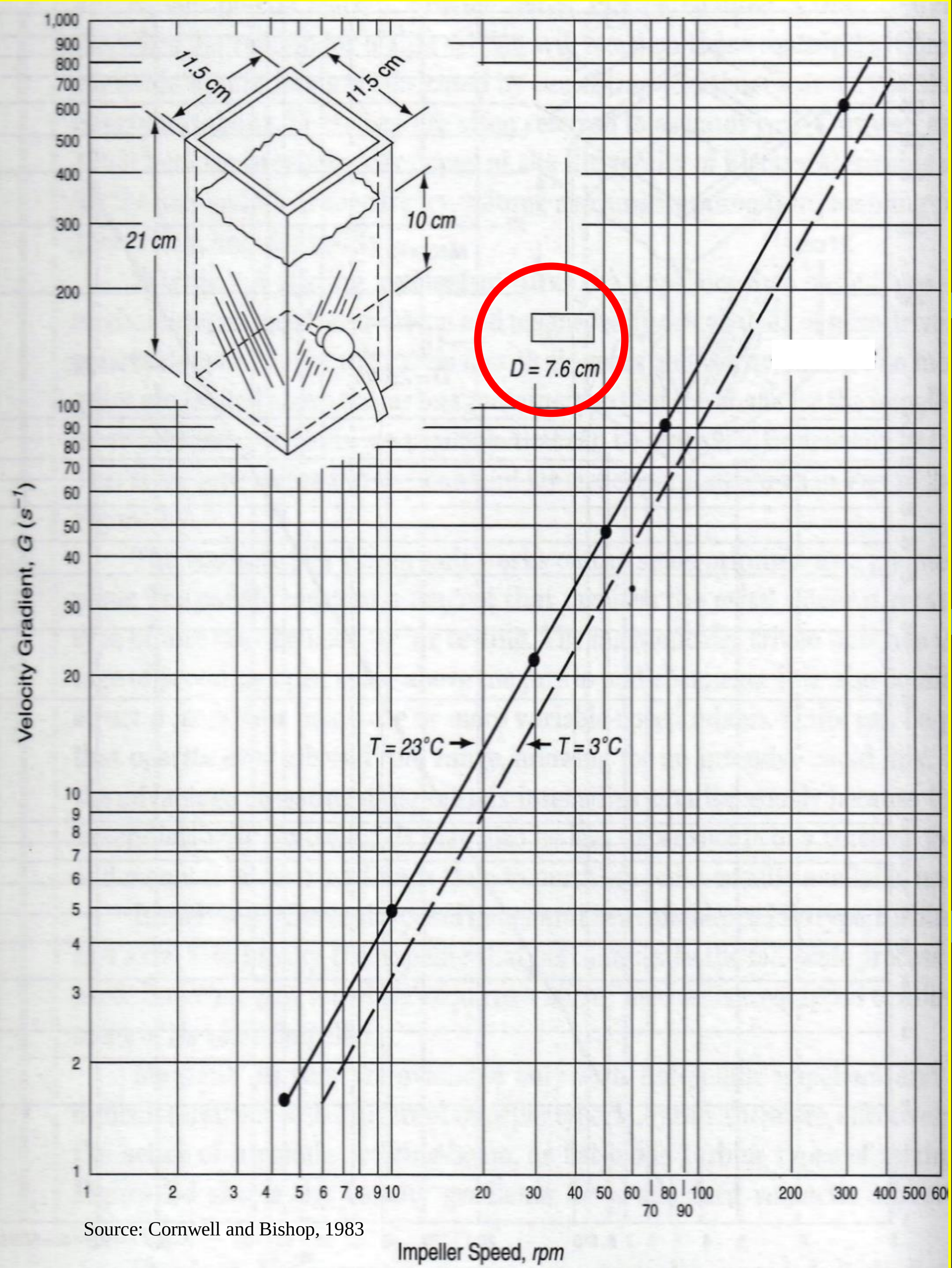
Chart X axis on bottom for the corresponding jar tester paddle speed needed

Note: 2 diagonal lines – one for very cold water, and one for warm water.

Using the G value on the y axis, follow the horizontal line until it hits a temperature line, then go straight down to get the paddle speed.

Example: warm water, and a G of 600 would require a jar mixer speed of 300

If WTP G value is higher than the paddle speed can achieve, use G X T to increase the amount of time that you mix on the jar tester.



Source: Cornwell and Bishop, 1983

Example using G x T Calculation

- Say the full-scale detention time through rapid mix is 30 seconds, and the G value for it is 1,000. But your jar tester can only operate at a speed of 300, so the corresponding warm-water full-scale G would be 600 according to the chart. What do you do?
  1. Set the equation:
     1. (1,000 ● 30 sec) = (600 ● X sec)
     2. X = 50 sec
  2. Operate the jar tester at 300 speed for 50 seconds

MAKING A BENCH SHEET

Aquarius Bench Sheet for Detention Times and Paddle Speeds, and Settling Time for Jars Using Plant-Scale SOR

Mixing, coagulation, and flocculation type zones 1,2,3, 4 and 5

- Detention Times in minutes
- Zone 1 DT = (5,056 gals) (#)/(flow rate, gpm) =

Time 1 box Paddle rpm from chart = ?

- Zones 2,3,4 and 5 DT = (26,330 gals)(# of flocs) / (flow rate, gpm) =

Time 2 box Paddle rpm from chart = ?

Time 3 box Paddle rpm from chart = ?

Time 4 box Paddle rpm from chart = ?

Time 5 box Paddle rpm from chart = ?

- SOR used for Settling Time

1. Basin SOR = (gpm) / (190' x 41')(# basins) = ____ gpm/sq ft
2. Settling velocity in cm/min = 4.07 x SOR
3. Settling time in minutes = 10 cm / settling velocity

Settling Time =

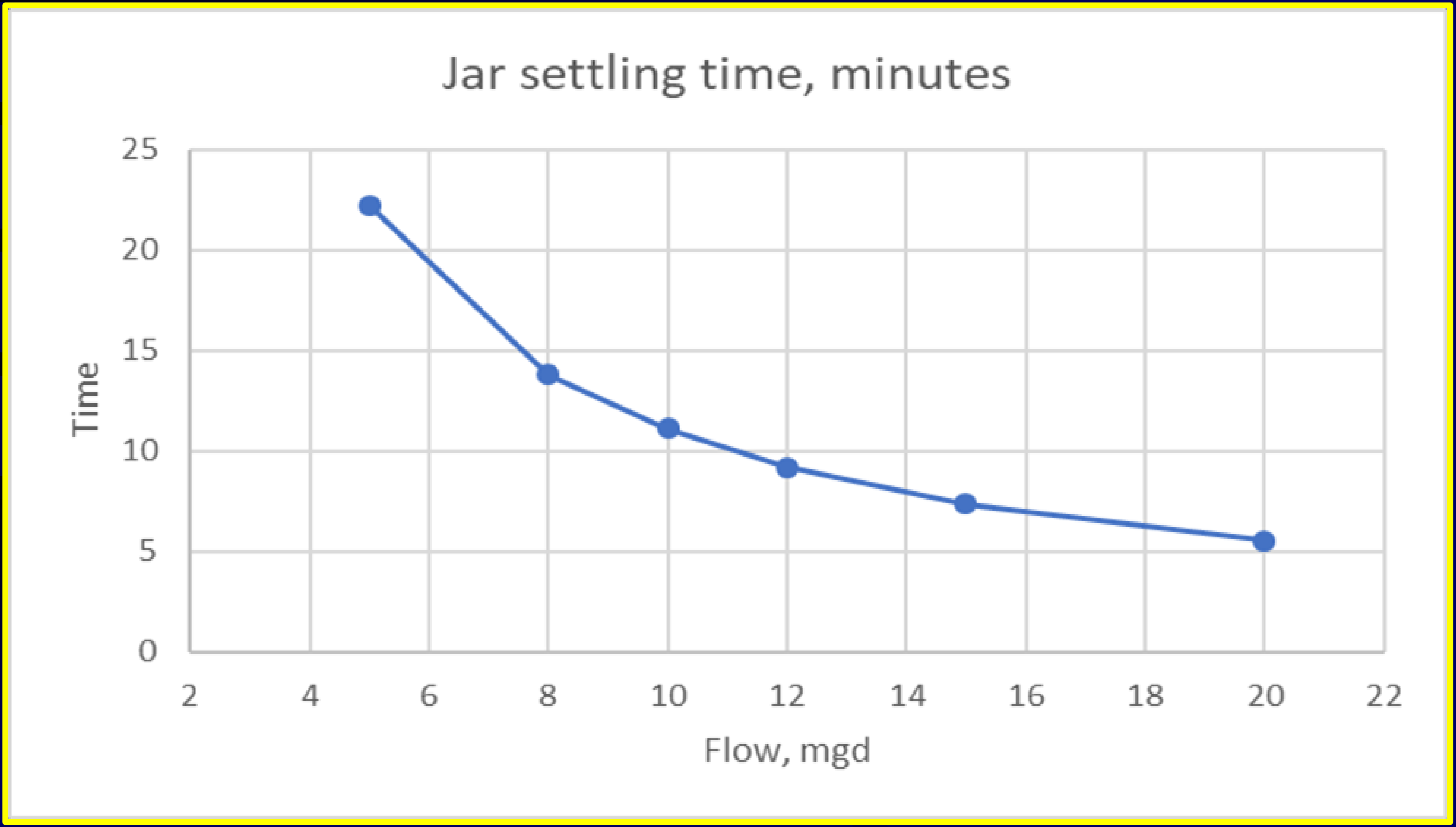
LET THE JARS SETTLE FOR THIS AMOUNT OF TIME AND THEN SAMPLE THEM SIMULTANEOUSLY

Time 6 box

Settling type zones - 6

Operator Guide Chart for Jar Settling Times
Aquarius WTP – a 20 mgd WTP

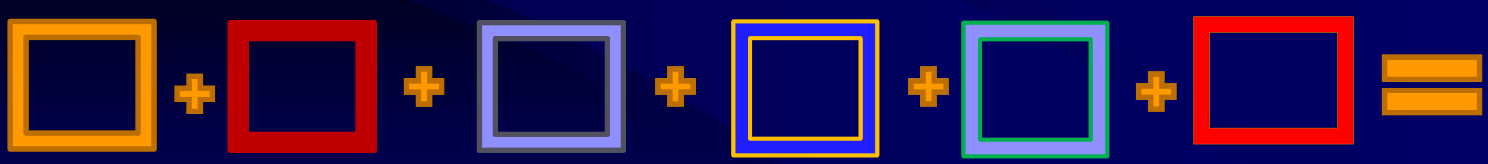
(all mixers, flocs, and sed basins in service)



Example of Total Time for Aquarius Jar Test

- Transfer data from Bench Sheet using color-coded boxes
- The sum of time in the boxes gives you an idea how long it will take, and box 6 tells you how long you should let the jars settle with no mixing before you sample.

Time =



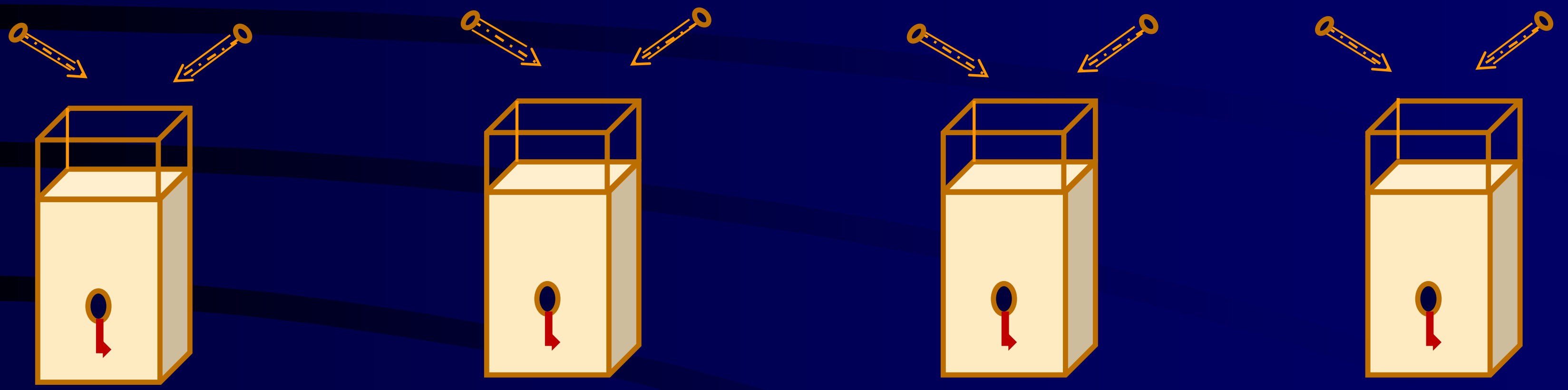
time box 1 time box 2 time box 3 time box 4 time box 5 time box 6 = Total time

Alum with permanganate, PAC and Cl_2 dose B4 test: (show variant)

Sample Jar Test Result Form for Aquarius Plant

Date: ______________________ **Reason for Test:** ___________________________

Jar 1	Jar 2	Jar 3	Jar 4
Mg/L Alum | mg/L Cl_2	Mg/L Alum | mg/L Cl_2	Mg/L Alum | mg/L Cl_2	Mg/L Alum | mg/L Cl_2



Jar 1	**Jar 2**	**Jar 3**	**Jar 4**
Sample	Sample	Sample	Sample
Other dose: ___________	Other dose: ___________	Other dose: ___________	Other dose: ___________
NTU:____________	NTU:____________	NTU:____________	NTU:____________
CL2:____________	CL2:____________	CL2:____________	CL2:____________

Is increase or decrease of alum or warranted? Y N Action taken? ________________________________

EQUIPMENT AND LAB APPARATUS

Jar Test Equipment

Jar Testing apparatus	Square 2 Liter Gator Jar. Note the sample port at the 10 cm mark	Syringe type pipettes suitable for use with jar test stock solutions

Various "TD" pipettes

Various "TC" volumetric flasks

STOCK SOLUTIONS

Definition

- **Stock solution**
  - a concentrated **solution** that will be diluted to some lower concentration for actual use
- **Stock solutions** are used to
  - save **preparation** time,
  - conserve materials,
  - reduce storage space,
  - and improve the accuracy with which working lower concentration **solutions** are prepared

Making Chlorine stock

If your plant treats with chlorine gas, you can use this method

1. Use commercial CLOROX, which (shown at right) is 8.25% as NaOCl
   a. Molecular weight of chlorine gas is 71, and NaOCl is 74.5
   b. 82,500 mg/L NaOCl X (71/74.5) = 78,624 mg/L expressed as Cl_2
2. To make a 2,000 mg/L stock, add 25.5 mLs bleach to 1 L DI water
   a. (25.5 mL x 78,624 mg/L) ÷ (1000 mL/L), so Strength ≈ 2,000 mg/L or 2 mg/mL

1 mL of stock into 2 Liter Gator Jar is 1 mg/L dose

Check strength of stock by adding 1 mL of 2,000 mg/L stock to 1 L DI – measure residual

This should yield a residual of 2 mg/L (because no demand) – if not, make adjustments

1. Note strength which is 8.25% - this may vary
   - It must say "regular", so no detergent is in it
2. It can come in several strengths, so observe closely

Important Note : Hypo vs. Chlorine Gas

- If your WTP used gaseous chlorine in pre-treatment, it likely depresses pH
- If you use hypochlorite at the Jar Scale to substitute for gaseous chlorine, it will likely elevate the pH
- Determine if this is a problem that you need to address

Making Alum stock – alternative method not shown in M37

- Use commercial liquid alum, which is, say, 48.8% dry-basis alum
- This product would be approximately 642 G/L. or 642 mg/mL dry-basis alum
  - Proof: this product weighs about 11 pounds per gallon (sp. gr. 1.325 X 8.34) = about 11 pounds per gallon
  - 11 pounds per gallon X 48.8% = 5.36 pounds dry alum per gallon
  - Therefore: 5.36 lbs. dry alum per gallon X (1 gal/3.785 L) X (453.6 grams/lb) = 642 grams/L, or 642 mg/mL

- So to make up a Liter of alum stock for Jar Test:
  - Add 15.6 mLs of liquid alum to a 1 Liter volumetric flask
  - Fill to the mark with lab grade water – mix thoroughly after "stoppering" the flask
  - This is: 15.6 mLs X 642 mg/mL = approximately 10,000 mg/Liter, or 10 mg/mL dry basis alum
  - Each mL of this stock added to a 2 Liter Gator Jar is a dose of 5 mg/L

Reason I Use a Different Alum Stock Formula

Step 1 - D/DBPR requires TOC removal:

	Source Water Alkalinity		
	0-60	> 60-120	> 120
Source Water TOC, mg/L ↓	Required % Removal		
> 2.0 - 4.0	35%	25%	15%
> 4.0 - 8.0	40%	35%	25%
> 8.0	50%	40%	30%

TOC Removal requirements

Step 2 - Alternative Criteria

Rule says that if you can't meet removal %, then:

1. Must meet one of six alternative compliance criteria
   a. Example: low SUVA value, low TTHM/HAA_5
2. **Step 3** - If that can't be met, WTP must determine its Enhanced Coagulation Endpoint (pH shown on next slide)
   a. endpoint is met when TOC is not reduced more than 0.3 mg/L **at incremental dosages of 10 mg/L dry-basis Alum**

Enhanced Coagulation Endpoint cont ….

The table on the right shows the lowest coagulation zone pH that must be met if a Utility needs to attain the "Enhanced Coagulation Endpoint"

The combination of coagulant, or coagulant with acid addition, that produces the pH needed can be determined by Jar Testing rather than by a full-scale demonstration

Alkalinity, mg/L	pH value
0 – 60	5.5
>60 – 120	6.3
>120 – 240	7.0
>240	7.5

Making stocks of dry chemicals

- For dry chemicals such as activated carbon, potassium permanganate, etc.
  - weigh 1 gram of the powder and transfer to a 1 Liter volumetric flask for 1 mg/mL stock
  - Add lab grade water up to the mark
  - 2 mLs of this transferred to a 2 Liter jar is a dose of 1 mg/L
- Take care when weighing the material, transferring it to the flask, and dissolving/dispersing

2 mLs

Final Thoughts

- You should be able to clearly define the reason you are running a jar test, e.g.….
  - What is the chlorine demand?
  - What is the best coagulant dosage for current conditions?
  - How much more TOC can be removed ?
- Never have more than one variable from jar to jar
  - Except for the variable, all jars need to be dosed the same, mixed the same, settled the same
- Keep records of the tests in a notebook – it may save you from doing future tests
- Keep it as simple as possible

Nick Pizzi email: nick@aqsrv.com

QUESTIONS?