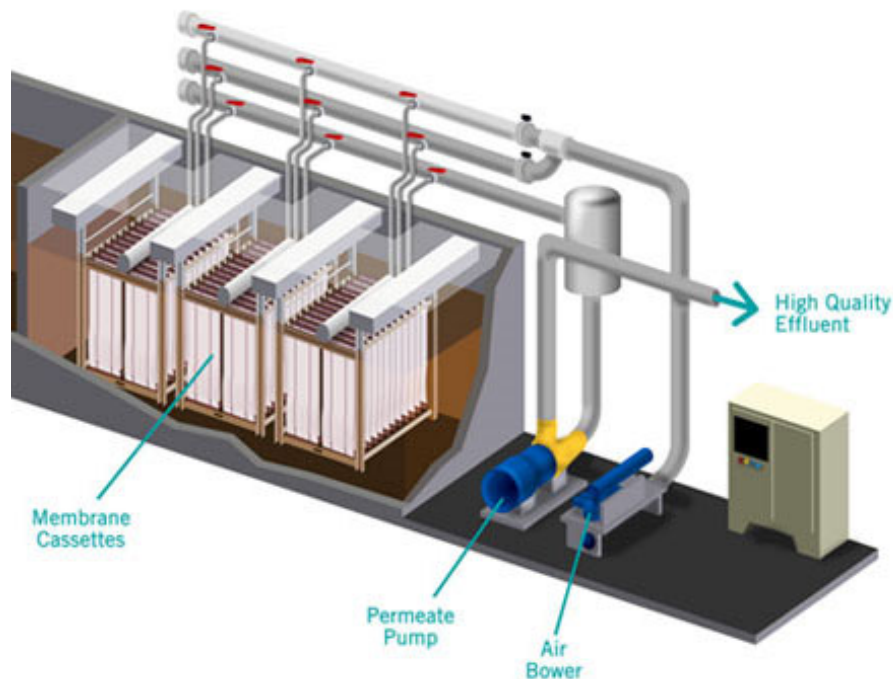


Advanced Water Treatment

Course # 302





Department of
**Environment &
Conservation**

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Section 1

Chemistry

 	
<h1>Chemistry</h1>	
• AWWA: Basic Science Concepts and Applications	

<h2>Objectives</h2> <ul style="list-style-type: none">• Structure of Matter• Classification of Matter• Chemical Formulas & Chemical Equations• Solutions• Acids, Bases, and Salts

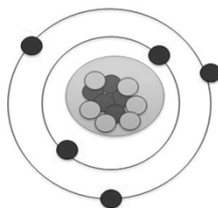
Structure of Matter



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Structure of Matter

- Atom
 - Smallest particle that still retains the characteristics of the element it is taken from
 - Comes from Greek word *atomos* meaning “uncut” or “indivisible”
 - Can be broken down into subatomic particles
- Atomic Structure
 - Proton
 - Neutron
 - Electron

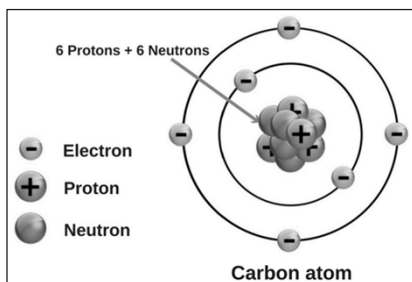


⊕ Protons

○ Neutrons

⊖ Electrons

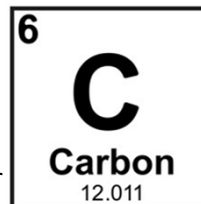
Structure of Matter



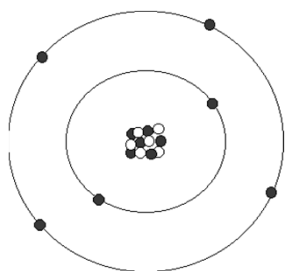
- Nucleus
 - Center of atom
 - Made up of positively charged protons and uncharged particles called neutrons
- Electrons
 - Occupy space surrounding nucleus
 - Make up most of the volume of the atom
 - Occupy space in “shells”

Structure of Matter

- Atomic Number
 - Indicates the number of protons inside the nucleus
 - i.e., Carbon = 6
- Atomic Weight
 - The sum of the number of protons and the number of neutrons in the nucleus
 - i.e., Carbon has 6 protons, therefore it will have 6 neutrons as well
 - Therefore, atomic weight = 12
 - Just a comparison between the weight of one atom and another



Structure of Matter



- Ions
 - Created when an atom is no longer electrically balanced
 - #protons does not equal # electrons
 - Cation – net positive charge
 - # protons > # electrons
 - Anion – net negative charge
 - # electrons > # protons
- During chemical reactions, only electrons interact and only those in the outermost shell

The Periodic Table

- A table that arranges atoms according to the number of electron shells they have and according to similarities of chemical properties
- Horizontal rows are called periods
 - Elements of same period have same number of electron shells
 - e.g. hydrogen and helium
- Vertical columns are called groups
 - Elements of same group have similar chemical properties
 - e.g. chlorine and iodine
- Basic information included in most periodic tables:

the element	Carbon
atomic number (# of protons)	6
symbol	C
atomic mass	12.011

Periodic Table of Elements

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	*La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	+Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110	111	112	113					

* Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+ Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Classification of Matter



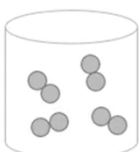
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Classification of Matter

- Matter
 - Anything that occupies space and has weight
 - Exists as solids, liquids, or gases
- Pure Elements
 - e.g. carbon, oxygen
 - Most elements are unstable and combine with other elements to form compounds



Atoms



Molecules



Compound



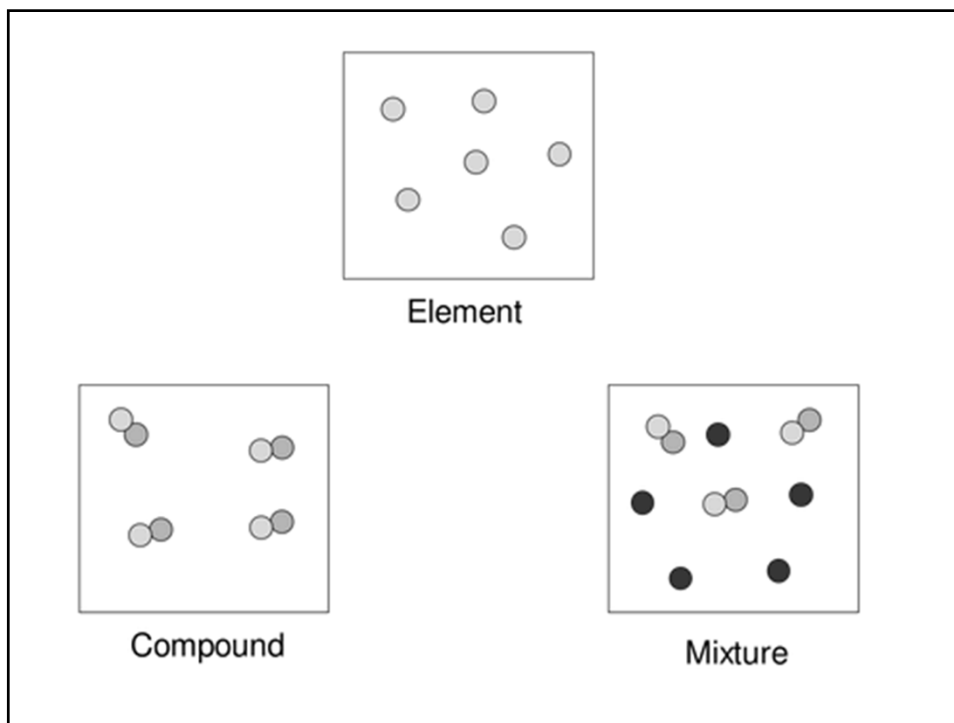
Mixture

Classification of Matter

- Compounds
 - Two or more elements bonded together by a chemical reaction
 - Ionic bond between elements
- Molecule
 - Formed when atoms of two or more elements are bonded together to form a compound
 - e.g., water (H_2O), carbon dioxide (CO_2), oxygen (O_2)
 - Molecular bond between elements

Classification of Matter

- Mixtures
 - Result of two or more elements and/or compounds mixed, and no chemical reaction occurs (no bonding)
 - Can be separated back to original elements/compounds
 - e.g., air, glass, steel



Chemical Formulas & Chemical Equations

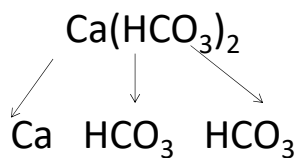
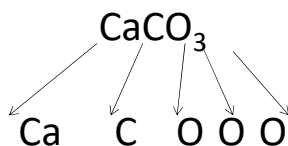


Chemical Formulas

- Simplest molecule contains only one type of atom
 - e.g., O_2 , Cl_2
- Molecules - compounds made up of at least two different elements
 - e.g., H_2O
- Chemical formula - tells what elements are present and how many of each atom of each element are present

Reading Chemical Formulas

- CaCO_3
- Letters indicate atoms present in compound
 - Calcium
 - Carbon
 - Oxygen
- Subscripts (numbers) indicate number of each atom
 - 1 calcium
 - 1 carbon
 - 3 oxygen



Calcium bicarbonate contains:

1 calcium atom
2 hydrogen atoms
2 carbon atoms
6 oxygen atoms

Determining Percent by Weight of Elements in a Compound

- If 100 lb of sodium chloride (NaCl) were separated into the elements that make up the compound, there would be 39.3 lb of pure sodium and 60.7 lb of pure chlorine
 - 39.3% sodium by weight
 - 60.7% chlorine by weight
- Percent by weight determined by using the compound's chemical formula and atomic weights from the periodic table

Determining Percent by Weight of Elements in a Compound

- First count how many atoms of each element in a single molecule: NaCl
 - Na – 1 atom
 - Cl – 1 atom
- Next, find the atomic weight of each atom, using the periodic table
 - Atomic weight of Na = 22.99
 - Atomic weight of Cl = 35.45

11	17
Na	Cl
Sodium	CHLORINE
22.990	35.453

Determining Percent by Weight of Elements in a Compound

- Finally, find atomic weight by the number of atoms of that element in the molecule, and the total weights:

	Number of Atoms		Atomic Weight		Total Weight
Sodium (Na)	1	X	22.99	=	22.99
Chlorine (Cl)	1	X	35.45	=	35.45
Molecular weight of NaCl				=	58.44

Determining Percent by Weight of Elements in a Compound

NaCl

$$\% \text{ by weight} = \frac{\text{weight of element in compound}}{\text{molecular weight of compound}} \times 100$$

$$\text{percent Na by weight} = \frac{22.99}{58.44} \times 100 = 39.3\%$$

$$\text{percent Cl by weight} = \frac{35.45}{58.44} \times 100 = 60.7\%$$

$$100.00\%$$

Determining Percent by Weight of Elements in a Compound

- Finally, find atomic weight by the number of atoms of that element in the CaCO_3 molecule, and the total weights:

	Number of Atoms		Atomic Weight		Total Weight
Calcium (Ca)	1	X	40.08	=	40.08
Carbon (C)	1	X	12.01	=	12.01
Oxygen	3	X	16.00	=	48.00
Molecular weight of CaCO_3					= 100.09

Determining Percent by Weight of Elements in a Compound - Example

$$\text{CaCO}_3 \% \text{ by weight} = \frac{\text{weight of element in compound}}{\text{molecular weight of compound}} \times 100$$

$$\text{percent Ca by weight} = \frac{40.08}{100.09} \times 100 = 40\%$$

$$\text{percent C by weight} = \frac{12.01}{100.09} \times 100 = 12\%$$

$$\text{percent O by weight} = \frac{48.00}{100.09} \times 100 = 48\%$$

$$100.00\%$$

Chemical Formulas

- You can now take that data and determine the actual weight of any element present

Example

- You have 50 lb of CaCO_3 . How many pounds of each element in the compound do you have?

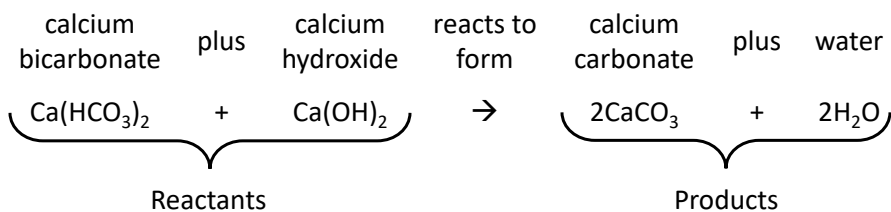
$$\% \text{ Ca by weight} = (0.40)(50\text{lb}) = 20 \text{ lb}$$

$$\% \text{ C by weight} = (0.12)(50\text{lb}) = 6.0 \text{ lb}$$

$$\% \text{ O by weight} = (0.48)(50\text{lb}) = 24 \text{ lb}$$

Chemical Equations

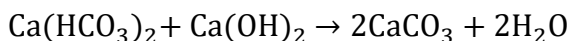
- Chemical equations use chemical formulas to write the reaction that takes place when certain chemicals are brought together



- "2" in front of CaCO_3 is a coefficient and indicates the number of molecules of CaCO_3 are involved

Chemical Equations

- Matter is neither created nor destroyed therefore the number of atoms of each element going into the reaction must be the same as the number coming out
 - Equation must **balance**
- If you calculate the total molecular weight of the reactants, it will be equal to the total molecular weight of the products
 - Chemicals shown in the equation will always react in the proportions indicated by their weights
 - Example



Chemical Equations

- Calculate the molecular weight for each of the four terms.

$$\text{Ca}(\text{HCO}_3)_2 = 162.12$$

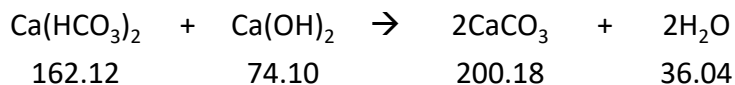
$$\text{Ca}(\text{OH})_2 = 74.10$$

$$\text{CaCO}_3 = 100.09$$

$$100.09 \times 2 = 200.18$$

$$\text{H}_2\text{O} = 18.02$$

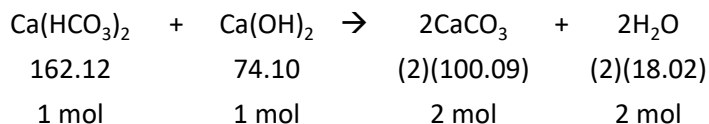
$$18.02 \times 2 = 36.04$$



- Given 162.12 lb of $\text{Ca}(\text{OH})_2$, you must add 74.10 lb of $\text{Ca}(\text{HCO}_3)_2$ for a complete reaction

Definition of a Mole

- A mole of a substance is a number of grams of that substance, where the number equals the substance's molecular weight



- Could be stated:
 - One mole of calcium bicarbonate is needed to react with one mole of calcium hydroxide, and the reaction yields two moles of calcium carbonate and two moles of water
- The weight of a mole of a substance depends on what the substance is

Mole

$$\text{number of moles} = \frac{\text{total weight}}{\text{molecular weight}}$$

Example:

- If 150 g of sodium hydroxide (NaOH) is mixed into water to make a solution, how many moles of solute have been used? (atomic weights: Na=22.99; O=16.00; H=1.01)

$$\text{molecular weight of NaOH} = 40.00$$

$$\text{number of moles} = \frac{150 \text{ g}}{40.00 \text{ g/mol}}$$

$$= 3.75 \text{ mol of NaOH}$$

Solutions



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Solutions

- A **solution** consists of a solute dissolved into a solvent to form a uniform mixture
- In a true solution, the solute will not settle out
 - i.e. salt water
 - Sand mixed in water is not a solution as the sand will settle out
- Water is the most common solvent
 - Solute may be solid, liquid, or gases
- Solution concentration is the amount of solute dissolved in a given amount of solvent
 - Strong solution has high concentration of solute

Expressing Solution Concentrations

- Measured as:

mg/L	gpg	% strength
molarity (M)		normality (N)

- Percent Strength

- Expressed as percent by weight or percent by volume

- Molarity

- Molarity – number of moles of solute per liter of solution

$$\text{molarity (M)} = \frac{\text{moles of solute}}{\text{liters of solution}}$$

Normality

- Normality – number of equivalent weights per liter of solution

$$\text{normality} = \frac{\text{number of equivalent weights of solute}}{\text{liters of solution}}$$

Hardness

- Hardness – measure of the effects that water impurities such as magnesium and calcium have on corrosion, scaling, and soap
- Hard water – water that has noticeable effects associated with hardness
- Calcium carbonate (CaCO_3) is common cause of hardness
- Hardness is expressed in terms of mg/L as CaCO_3

Standard Solutions

- Any solution that has an accurately known concentration
 - Weight per unit volume
 - A chemical is weighed and then dissolved in solvent
 - Dilution
 - A given volume of existing standard solution is diluted with a measured amount of solvent
 - $N_1V_1=N_2V_2$
 - Reaction
 - A mixture of two solutions

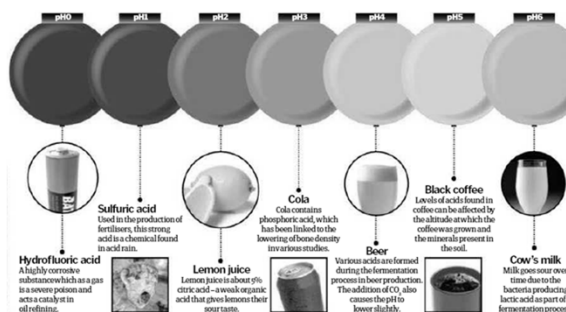
Acids, Bases, and Salts



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Acids

- Any substance that releases hydrogen ions (H^+) when it is mixed into water
 - Strong acids - acids that dissociate readily and release large amounts of H^+
 - Weak acids - acids that dissociate poorly
- Solutions that contain significant numbers of H^+ ions are called *acidic*

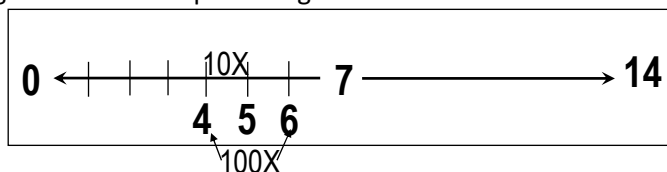


Bases and Salts

- Bases
 - Any substance that produces hydroxyl ions (OH^-) when mixed with water
 - Strong acids - acids that dissociate readily and release large amounts of H^+
 - Weak acids - acids that dissociate poorly
 - *Basic solutions* or *alkaline solutions* - solutions that contain significant numbers of OH^- ions
- Salts
 - Compounds resulting from an acid-base mixture
 - Process called neutralization
$$\text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}$$

pH

- A measurement of how acidic or basic a solution is
- pH scale runs from 0 (most acidic) to 14 (most basic)
 - Log scale means each pH measurement is 10 times greater than the preceding value



- Low pH can be increased by adding a base
 - OH^- ions released will combine with H^+ ions to form H_2O and lowering H^+ concentrations
- High pH can be decreased by adding an acid

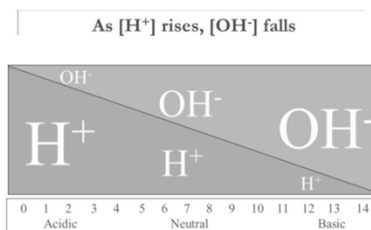
pH

- When there are exactly as many OH⁻ ion as H⁺ ions, the solution is *neutral*

– pH 7: H⁺ = 10⁻⁷ and OH⁻ = 10⁻⁷

– pH 4: H⁺ = 10⁻⁴ and OH⁻ = 10⁻¹⁰

– pH 10: H⁺ = 10⁻¹⁰ and OH⁻ = 10⁻⁴

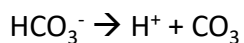
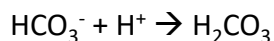


Alkalinity

- A measurement of a water's capacity to neutralize acid
 - The carbonate and bicarbonate ions increase the neutralization capacity
- Total alkalinity made up of
 - Hydroxyl (OH⁻) alkalinity
 - Carbonate (CO₃⁻²) alkalinity
 - Bicarbonate (HCO₃⁻) alkalinity

Alkalinity

- When an acid is added to water that is basic (high OH^-), the H^+ ions released by the acid combine with the OH^- in the water to form H_2O
- Alkalinity measured by bicarbonate (HCO_3^-)
 - Bicarbonate maintains pH by taking on or giving H^+



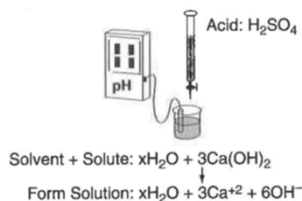
- This maintains the water at around pH 7

Alkalinity

- When acid is added to water that contains carbonate (CO_3^{2-}) ions in addition to OH^- , some bicarbonate (HCO_3^-) will be formed as well as H_2O
 - Additional acid will cause the excess H^+ ions to combine with the bicarbonate to form carbonic acid (H_2CO_3)
 - H^+ will begin to accumulate once all the OH^- has been converted to H_2O and all the carbonate (CO_3^{2-}) converted to bicarbonate (HCO_3^-) and then to carbonic acid (H_2CO_3)

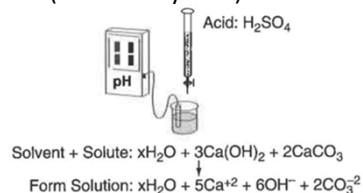
• Solution 1

- Equal volumes of a base (lime) and water are mixed
- pH = 11
- All alkalinity is hydroxyl alkalinity



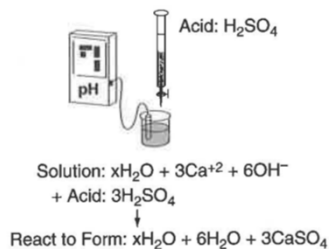
• Solution 2

- Lime and calcium carbonate are mixed
- pH = 11
(Therefore OH^- concentration is same as solution 1)
- Higher alkalinity due to carbonate ions (released by CaCO_3) as well as OH^- (released by lime)



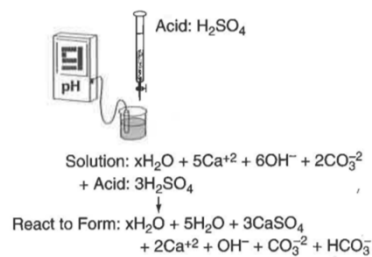
• Solution 1

- Add sulfuric acid until pH = 7
 - Enough H^+ added to combine with all OH^-



• Solution 2

- Add same quantity of sulfuric acid as Solution 1
 - pH > 7
 - H^+ combined with carbonate decreasing reaction with OH^-
- Sulfuric acid is added to bring pH = 7



Section 1 Chemistry Vocabulary

- Acid
- Alkalinity
- Anion
- Atom
- Atomic Number
- Atomic Weight
- Base
- Cation
- Chemical Equation
- Chemical Formula
- Chemical Symbol
- Coefficient
- Compound
- Concentration
- Electron
- Haloacetic Acids (HAA5)
- Inorganic Compound
- Ion
- Matter
- Maximum Contaminant Level (MCL)
- Mixture
- Mole
- Molecular Weight
- Molecule
- Neutron
- Normality
- Nucleus
- Organic Compound
- Percent by Weight
- Periodic Table
- pH
- Proton
- Solute
- Solution
- Solvent
- Synthetic Organic Chemical (SOC)
- Trihalomethanes (THM)

- _____ 1. The smallest particle of an element that still retains the characteristics of that element.
- _____ 2. A positively charged particle located in the nucleus of an atom.
- _____ 3. An uncharged elementary particle that has a mass approximately equal to that of the proton.
- _____ 4. A tiny, negatively charged particle that orbits around the nucleus of an atom.
- _____ 5. The center of an atom, made up of protons and neutrons.
- _____ 6. The number of protons in the nucleus of an atom.
- _____ 7. The sum of the number of protons and the number of neutrons in the nucleus of an atom.
- _____ 8. An atom that is electrically unstable because it has more or fewer electrons than protons.
- _____ 9. A positive ion.
- _____ 10. A negative ion.

- _____ 11. A chart showing all elements arranged according to similarities of chemical properties.
- _____ 12. The standard abbreviation for an element, either one or two letters.
- _____ 13. Anything that occupies space and has weight (mass).
- _____ 14. Two or more elements bonded together by a chemical reaction.
- _____ 15. Two or more atoms joined together by a chemical bond.
- _____ 16. Two or more elements, compounds, or both, mixed together with no chemical reaction or bonding occurring.
- _____ 17. Using the chemical symbols for each element, a shorthand way of writing what elements and how many elements of each are present in a molecule.
- _____ 18. The proportion, calculated as a percentage, of each element in a compound.
- _____ 19. The sum of the atomic weights of all the atoms in the compound.
- _____ 20. A shorthand way, using chemical formulas, of writing the reaction that takes place when chemicals are brought together.
- _____ 21. An indication of the relative number of molecules of the compound that are involved in the chemical reaction.
- _____ 22. The quantity of a compound or element that has a weight in grams equal to the substance's molecular or atomic weight.
- _____ 23. The number of equivalent weights of solute per liter of solution.
- _____ 24. A liquid containing a dissolved substance.
- _____ 25. The liquid used to dissolve a substance.
- _____ 26. The substance dissolved in a solution.
- _____ 27. A measurement of how much solute is contained in a given amount of solvent; commonly measured as mg/L.

- _____ 28. A chemical substance of mineral origin not having carbon in its molecular structure.
- _____ 29. Any substance that releases hydrogen ions (H^+) when it is mixed into water.
- _____ 30. Any substance that produces hydroxide ions (OH^-) when it dissociates in water.
- _____ 31. A measurement of how acidic or basic a substance is.
- _____ 32. A measurement of water's capacity to neutralize an acid.
- _____ 33. A chemical substance of animal or vegetable origin having carbon in its molecular structure.
- _____ 34. Disinfection by-product compounds formed by the reaction of organic material in water with chlorine, consisting of chloroform, dichlorobromomethane, bromodochloromethane, and bromoform.
- _____ 35. The maximum permissible level of a contaminant in water as specified by the SDWA.
- _____ 36. Chemicals formed as a reaction of disinfectants with contaminants in water, consisting of monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid.
- _____ 37. A chemical produced by humans that can contaminate water.

Section 1 Chemistry Vocabulary - Answers

- | | |
|-----------------------|--------------------------------------|
| 1. Atom | 19. Molecular Weight |
| 2. Proton | 20. Chemical Equation |
| 3. Neutron | 21. Coefficient |
| 4. Electron | 22. Mole |
| 5. Nucleus | 23. Normality |
| 6. Atomic Number | 24. Solution |
| 7. Atomic Weight | 25. Solvent |
| 8. Ion | 26. Solute |
| 9. Cation | 27. Concentration |
| 10. Anion | 28. Inorganic Compound |
| 11. Periodic Table | 29. Acid |
| 12. Chemical Symbol | 30. Base |
| 13. Matter | 31. pH |
| 14. Compound | 32. Alkalinity |
| 15. Molecule | 33. Organic Compound |
| 16. Mixture | 34. Trihalomethanes (THM) |
| 17. Chemical Formula | 35. Maximum Contaminant Level (MCL) |
| 18. Percent by Weight | 36. Haloacetic Acids (HAA5) |
| | 37. Synthetic Organic Chemical (SOC) |

Periodic Table of the Elements

<http://chemistry.about.com>
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 About Chemistry

1A																	8A					
1 H 1.00794																	2 He 4.002602					
2A																	3A	4A	5A	6A	7A	
3 Li 6.941	4 Be 9.012182											5 B 10.811	6 C 12.0107	7 N 14.0067	8 O 15.9994	9 F 18.9984032	10 Ne 20.1797					
11 Na 22.989769	12 Mg 24.3050	3B	4B	5B	6B	7B	8B			1B	2B	13 Al 26.9815386	14 Si 28.0855	15 P 30.973762	16 S 32.065	17 Cl 35.453	18 Ar 39.948					
19 K 39.0983	20 Ca 40.078	21 Sc 44.955912	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.938045	26 Fe 55.845	27 Co 58.933195	28 Ni 58.6934	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.64	33 As 74.92160	34 Se 78.96	35 Br 79.904	36 Kr 83.798					
37 Rb 85.4678	38 Sr 87.62	39 Y 88.90585	40 Zr 91.224	41 Nb 92.90638	42 Mo 95.96	43 Tc [98]	44 Ru 101.07	45 Rh 102.90550	46 Pd 106.42	47 Ag 107.8682	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.90447	54 Xe 131.293					
55 Cs 132.9054519	56 Ba 137.327	57-71 Lanthanides	72 Hf 178.49	73 Ta 180.94788	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.084	79 Au 196.966569	80 Hg 200.59	81 Tl 204.3833	82 Pb 207.2	83 Bi 208.98040	84 Po [209]	85 At [210]	86 Rn [222]					
87 Fr [223]	88 Ra [226]	89-103 Actinides	104 Rf [267]	105 Db [268]	106 Sg [271]	107 Bh [272]	108 Hs [270]	109 Mt [276]	110 Ds [281]	111 Rg [280]	112 Cn [285]	113 Uut [284]	114 Fl [289]	115 Uup [288]	116 Lv [293]	117 Uus [294]	118 Uuo [294]					

Lanthanides

57 La 138.90547	58 Ce 140.116	59 Pr 140.90765	60 Nd 144.242	61 Pm [145]	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92535	66 Dy 162.500	67 Ho 164.93032	68 Er 167.259	69 Tm 168.93421	70 Yb 173.054	71 Lu 174.9668
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Actinides

89 Ac [227]	90 Th 232.03806	91 Pa 231.03588	92 U 238.02891	93 Np [237]	94 Pu [244]	95 Am [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [257]	101 Md [258]	102 No [259]	103 Lr [262]
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Section 2

Equipment Maintenance

California State University, Sacramento	
Water Treatment Plant Operations Vol. II	
	
<h1>Maintenance</h1>	
1	

TDEC - Fleming Training Center	2
<h2>Treatment Plant Maintenance</h2>	
<ul style="list-style-type: none">• A good maintenance program is a must in order to maintain successful operation of a water plant• Should include everything from mechanical equipment to the care of the plant grounds, buildings and structures• Mechanical maintenance is of prime importance as the equipment must be kept in good operating condition in order for the plant to maintain peak performance	

Preventive Maintenance Records

- Preventive maintenance programs keep equipment in good working condition and correct small malfunctions before they turn into big problems
- A good record keeping system tells when maintenance is due and shows equipment performance
- Equipment service cards and service record cards should be filled out for each piece of equipment in the plant

Equipment Service Card

- Tells what should be done and when
- Should include equipment name
 - e.g. raw water intake pump No. 1
- List each required maintenance service with an item number
- List maintenance services in order of frequency of performance
- Describe each type of service under work to be done

5

EQUIPMENT SERVICE CARD

Equipment: #1 Raw Water Intake Pump

Item No.	Work to be done	Frequency	Time
1	Check water seal and packing gland	Daily	
2	Listen for unusual noises	Daily	
3	Operate pump alternately	Weekly	Monday
4	Inspect pump assembly	Weekly	Wednesday
5	Inspect and lube bearings	Quarterly	1, 4, 7, 10
6	Check operating temperature of bearings	Quarterly	1, 4, 7, 10
7	Check alignment of pump and motor	Semi-annually	4, 10
8	Inspect and service pump	Semi-annually	4, 10
9	Drain pump before shutdown		

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Service Record Card

- Tells what was done and when it was done
- Should have date and work done, listed by item number and signed by the operator who performed the service

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SERVICE RECORD CARD

Equipment: #1 Raw Water Intake Pump

Date	Work Done (Item No.)	Signed	
1-6-13	1-2-3	J.D.	
1-7-13	1-2	J.D.	
1-8-13	1-2-4-5-6	P. K.	

8

Electrical Equipment




Beware of Electricity

- Do not attempt to install, troubleshoot, maintain, repair, or replace electrical equipment, panels, controls, wiring, or circuits unless
 - You know what you are doing
 - You are qualified
 - You are authorized



Fundamentals of Electricity



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Volts

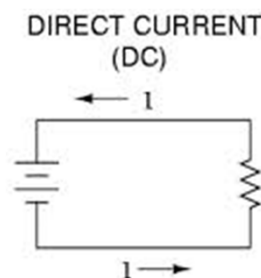
- Also known as electromotive force (EMF)
- The electrical pressure available to cause a flow of current (amperage) when a circuit is closed
- Voltage (E) is the force that is necessary to push electricity or electric current through a wire
- Two types:
 - Direct current (DC)
 - Alternating current (AC)

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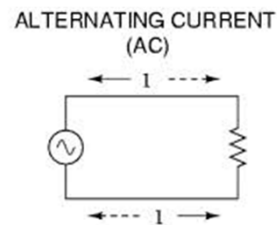
Direct Current (DC)

- Flow in one direction and is essentially free from pulsation
- Used exclusively in automotive equipment, certain types of welding equipment, and a variety of portable equipment
- Found in various voltages
 - 6, 12, 24, 48, and 110 volts
- All batteries are DC



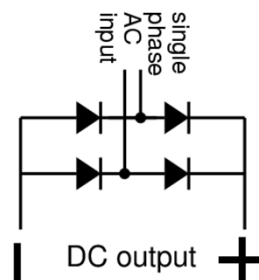
Alternating Current (AC)

- Voltage and current periodically change direction and amplitude
- Current goes from zero to maximum strength, back to zero, and to the same strength in the opposite direction
- Hertz describes the frequency of cycles completed per second
- Classified as
 - Single phase
 - Two phase
 - Three phase or polyphase



Alternating Current – Single Phase

- Found in lighting systems, small pump motors, various portable tools, and throughout homes
- Usually, 120 volts and sometimes 240 volts
- Only one phase of power is supplied to the main electrical panel

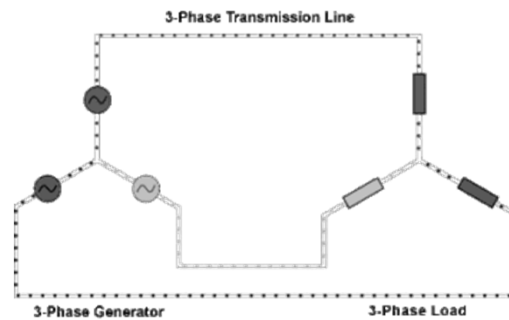


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Alternating Current – Three Phase

- Generally used with motors and transformers
- Usually is 208, 220, 240 volts, or 440, 460, 480, and 550 volts
- Used when high power requirements or larger motors are used
- Efficiency is higher and less maintenance is required
- Generally, all motors with > 2 HP are three phase

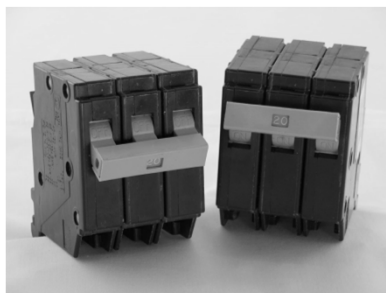


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Alternating Current – Circuit Breakers

- Used to protect electric circuits from overloads
- Metal conductors that de-energize the main circuit is overheated by too much current passing through



Amps

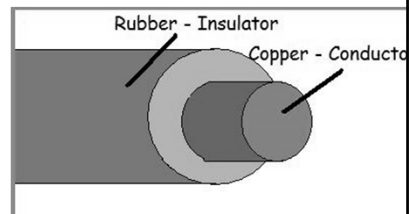
- The measurement of current or electron flow and is an indication of work being done or “how hard the electricity is working”
- The practical unit of electrical current

Watts (W) and Kilowatts(kW)

- The units of measurement of the rate at which power is being used or generated
- In DC circuits, watts equal the voltage times the current
$$\text{Watts} = (\text{volts})(\text{amps})$$
- In AC polyphase circuits, you have to include the power factor and the $\sqrt{3}$
$$\text{Watts} = (\text{volts})(\text{amps})(\text{power factor})(1.73)$$
- Power factor is the ratio of actual power passing through a circuit to the apparent power
 - Usually somewhere near 0.9

Conductors and Insulators

- Conductor - a material that allows the flow of electric current
e.g. copper
- Insulator - a material that will not allow the flow of electricity
e.g. rubber
 - Insulation commonly used to prevent the loss of electrical flow by two conductors coming into contact with each other



Tools, Meters and Testers



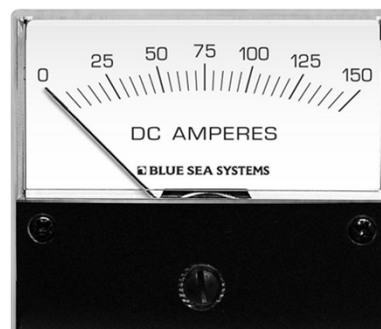
Voltage Testing

- Multimeter used for checking voltage
- Use meter that has sufficient range to measure voltage you would expect to find
- Tells if AC or DC and intensity or voltage
- Used to test for open circuits, blown fuses, single phasing of motors, grounds, etc.



Ammeter

- Records the current or “amps” flowing in the circuit
- Two common types:
 - Clamp-on type – used for testing
 - Clamped around a wire supplying a motor
 - In-line type – installed in a panel or piece of equipment
 - Connected in line with the power lead or leads



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Megger

- Used for checking the insulation resistance on motors, feeders, bus bar systems, grounds, and branch circuit wiring
- Connected to a motor terminal at the starter
- Test results show if the insulation is deteriorating or cut
- Three types
 - Crank operated
 - Battery operated
 - Instrument



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Ohmmeters

- Used to measure the resistance in a circuit
- Also called circuit testers
- Electrical circuit must be OFF to use ohmmeter
- Ohmmeter supplies own power



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Equipment Protective Devices



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Fuses

- A protective device having a strip or wire of fusible metal that will melt and break the electrical circuit when subjected to excessive temperature
- Common types:
 - Current-limiting fuses – used to protect power distribution circuits
 - Dual-element fuses – used for motor protection circuits
- Be sure to replace fuses with proper size and type indicated for that circuit

Overload Relays

- Heater strips open on current rise (overheating) and open the control circuit
 - This opens the power control circuit which de-energizes the start and stops power to the motor
- Also known as heaters or “thermal overloads”
- Range from 100-110 of the motor nameplate ratings
- Should never exceed 125% of the motor rating
- Never increase the rating of the overload relay
 - Find the problem that is causing it to trip and repair it
- Ground – an electrical connection to earth or a large conductor that is at the earth’s potential or neutral voltage

Overload Relays



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Auxiliary Electrical Power

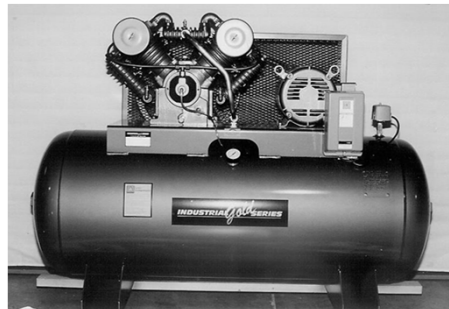
- Standby power generation – three types
 - Engine driven generator
 - Batteries
 - Alternate power source
- Emergency lighting
- Batteries

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Compressors

- A device used to increase the pressure of air or gas
- Consists of a suction pipe with a filter and a discharge pipe that connects to an air receiver
- Can be simple diaphragm type or complex rotary, piston, or sliding vane type



Compressor Maintenance

- Inspect the suction filter of the compressor monthly
 - Clean or replace filter every 3-6 months
- Lubrication must be inspected daily
 - Oil should be replaced every 3 months
- Cylinder or casing fins should be cleaned weekly
- Inspect unloader
 - If not working properly, compressor will not start, stall, or burn off belts if belt driven
- Test the safety valves weekly

Compressor Maintenance

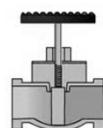
- Drain the condensate from air receiver daily
 - If has automatic drain, inspect periodically
- Inspect belt tension on compressor
 - Should be able to press the belt down, in the center, with your hand approximately $\frac{3}{4}$ inch
- Examine operating controls
 - Make sure compressor is starting and stopping at the proper settings
- Ensure portable compressors have oil in tool oiler reservoir
- Clean thoroughly each month

Valves



Gate Valves

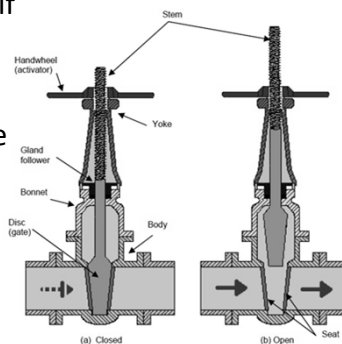
- Basic parts: operator (handle), shaft packing assembly, bonnet, valve body with seats, stem, and disc
- Valve disc is raised/lowered by a threaded shaft
- Disc is screwed down until it wedges itself between two machined valve seats
- Not used to control flows
- Either rising stem or non-rising stem type



Gate Valve Closed



Gate Valve Opened



Gate Valves – O & M

- 1. Open valve fully
- 2. Operate all large valves at least yearly to ensure proper operation
- 3. Inspect valve stem packing for leaks
- 4. If the valve has a rising stem, keep stem threads clean and lubricated
- 5. Close valves slowly in pressure lines to prevent water hammer
- 6. If a valve will not close by using the hand wheel, check for the cause; Using a “cheater” bar will only aggravate the problem

Gate Valves - Maintenance

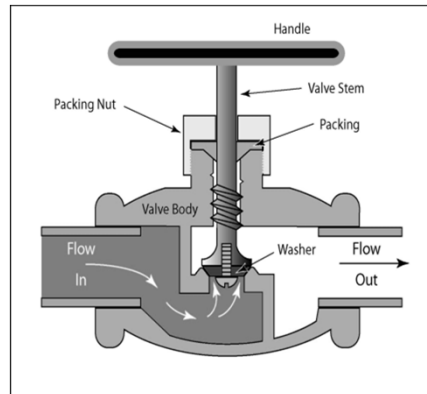
Frequency	Service
Annually	Replace packing: Remove all old packing from stuffing box. Insert new split ring packing while staggering the ring splits.
Semi-annually	Operate valve: Operate inactive gate valves to prevent sticking
Annually	Lubricate gearing: Lubricate gate valves as recommended by manufacturer
Semi-annually	Lubricate rising stem threads: Clean threads on rising stem gate valves and lubricate with grease
Annually	Reface leaky gate valve seats: Remove bonnet and clean examine disc body thoroughly. Check and service all parts of valve completely. Remove all old packing a clean out stifing box. Do not salvage old gasket. After cleaning and examining all parts, determine whether valve can be repaired or must be replaced. Test repaired valve before putting back in line.

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Globe Valves

- Use a circular disc to make a flat surface contact with a ground-fitted valve seat
- Internal design enables valve to be used in a controlling /throttling mode
- Can be of rising or nonrising stem type
- O & M similar to gate valve

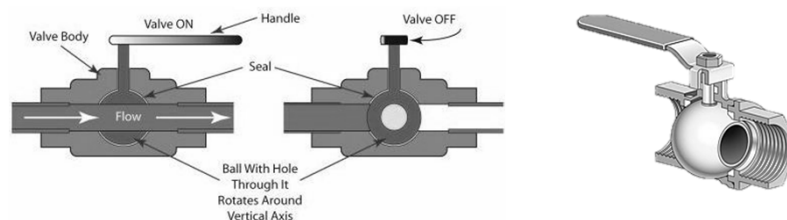


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Ball Valves

- A valve consisting of a ball resting in a cylindrical seat
- A hole is bored through the ball to allow water to flow when the valve is open
- When the valve is rotated 90°, the valve is closed
- Should be operated fully open or fully closed
 - Throttling can lead to damage to the seal

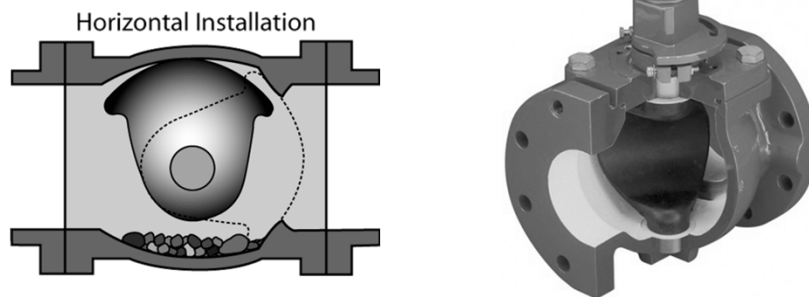


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Eccentric Valves

- Uses a cam shaped plug to match an eccentric valve seat
- As the valve is closed, the plug throttles the flow yet maintains a smooth flow rate
- Excellent for controlling the flows of slurries and sludges

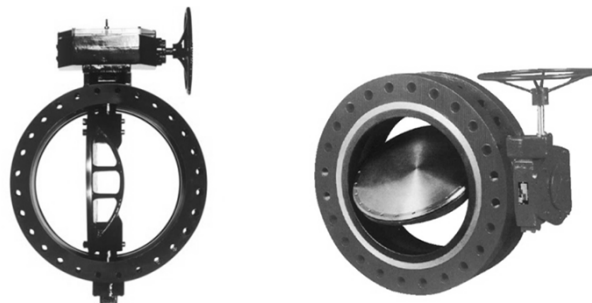


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Butterfly Valves

- Used primarily as a control valve
- Uses a machined disc that can be opened to 90° to allow full flow through valve
- Closed valve is forced against the continuous rubber seat

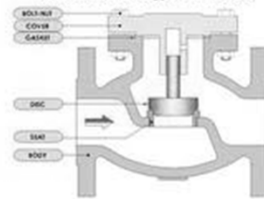


Check Valves

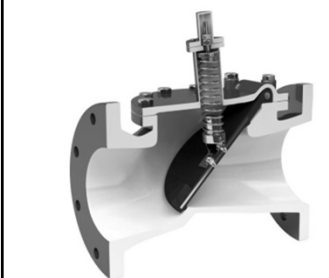
- Allows water to flow in only one direction
- Three types:
 - Swing check – a movable disc (clapper) rests at a right angle to the flow and seats against a ground seat
 - Wafer check – a circular disc that hinges in the center of the disc. Flow collapses the disc and flow stoppage allows the disc to return to its circular form
 - Lift check – uses a vertical lift disc or ball. Flow lifts the disc/ball and allows water to flow through.
 - Foot valves are nearly always vertical lift valves

Lift Check Valve

Check Valve Lift Type ASA-Model



© www.jdvalves.com



Swing Check Valve



Wafer Check Valve

Check Valves - Maintenance

Frequency	Service
Annually	Inspect disc facing: Open valves to observe condition of facing on swing check valves
Annually	Check pin wear: Check pin wear on balanced check valve, since disc must be accurately positioned in seat to prevent leakage

Chemical Storage and Feeders



Chemical Storage

- Hygroscopic chemicals absorb or attract moisture from the air
 - e.g. quicklime will generate tremendous heat when in contact with water
- Some liquid chemicals will form a solid or “freeze” if exposed to air
 - e.g. caustic soda will form calcium carbonate and sodium hydroxide will crystallize below 55°F

Chemical Storage

- Potassium permanganate can be stored for extended times in a cool, dry area in closed containers
 - Store in fire resistant building with concrete floors
 - Do not store near greases/oils or a heat source
 - Clean spill immediately by flushing away with water



Chemical Storage

- Carbon should be stored in a clean, dry place
 - Single or double rows with access around every stack
 - Storage area should be fire proof with self closing fire doors
 - Should be protected from contact with flammable materials
 - Keep oily rags and chlorine compounds away from area



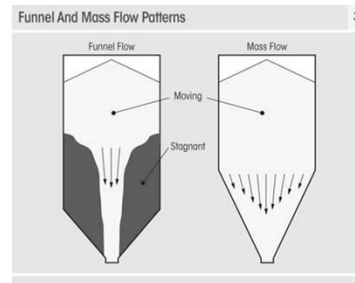
Chemical Storage

- Polymer solutions will lose their strength when exposed to biological contamination
 - Clean tanks before a new shipment is delivered
- Liquid chemical storage tanks should have a berm around the tanks to hold the amount stored (secondary containment)
- Continual surveillance and maintenance of storage and feeding systems are required



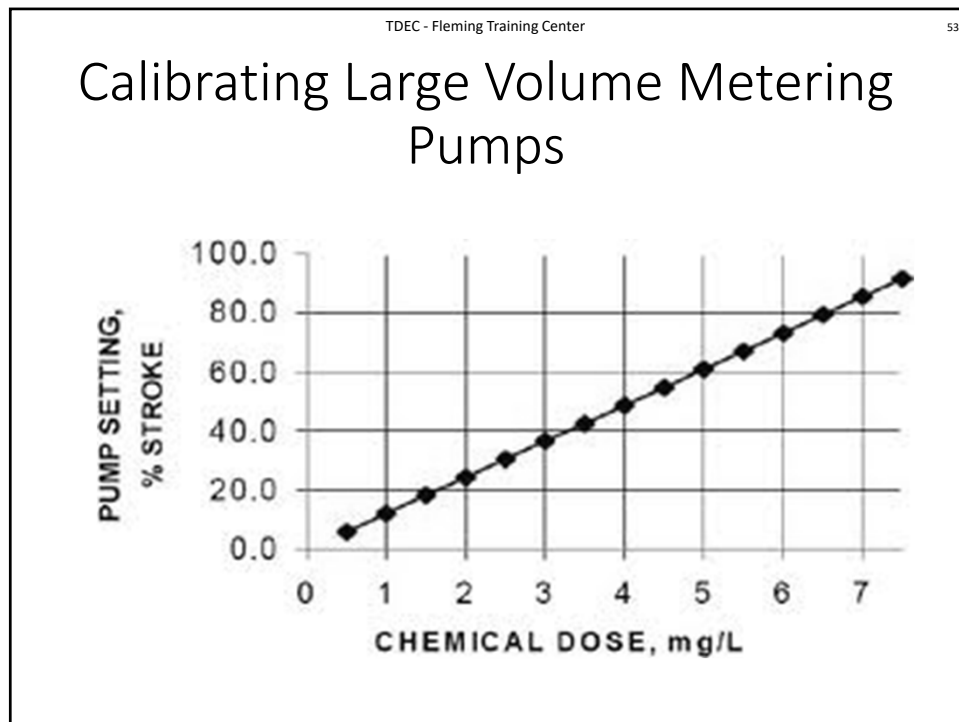
Chemical Storage

- Keep liquid feeders clean to prevent plugging or corrosion of the mechanism
- Single drain pit that can accept both acid and alkali chemicals is not allowed
- Solid chemical feeders should be kept clean and dry to prevent bridging of the chemical the hopper and clogging in the feeder
 - Bridging is a hardened layer that can form an arch and prevent flow



Calibrating Large Volume Metering Pumps

- Fill sight tube from the chemical solution tank
- Set valve so tube is only source of liquid chemical entering the pump
- Run the pump for set time at each representative setting of the pump control scale
- Use this info to develop curves of pump setting vs chemical dose in mg/L or gal/day
 - Called a calibration curve



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Calibrating Dry Chemical Systems

- Two common types:
 - Rocker-dump type – uses a scraper moving back and forth on a platform
 - Helix-feed type – uses a rotating screw (helix)
- To calibrate, catch the chemical fed at several representative settings during a measured time interval
- Weigh each volume and convert into lbs/day

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Chlorinators

- Chlorine gas leaks will cause equipment to corrode
 - A green or reddish deposit on metal indicates corrosion
- Ammonia vapor will detect any chlorine leak
 - Cloth soaked with diluted ammonia works as a leak detector
 - Wave cloth on a stick in general area of leak (do **not** touch equipment with it)
 - If there is a leak, a white cloud of ammonium chloride will form
- This should be done at all gas pipe joints, both inside and outside the chlorinators, at regular intervals

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Chlorinators

- New gaskets should be used for each new connection
- Water strainers may be cleaned by flushing with water
 - If badly fouled, clean with hydrochloric acid then rinse with water
- Atmosphere vent lines must be open and free
 - Should evacuate chlorine to outside when chlorinator is being shut down

Maintenance Vocabulary

A. Air Gap	J. Cycle	S. Lead
B. Alternating Current	K. Direct Current	T. Megger
C. Amperage	L. Electrolyte	U. Ohm
D. Ampere	M. Electromotive Force	V. Power Factor
E. Circuit	N. Electron	W. Prussian Blue
F. Circuit Breaker	O. Fuse	X. Resistance
G. Conductor	P. Ground	Y. Voltage
H. Coulomb	Q. Hertz	Z. Water Hammer
I. Current	R. Hygroscopic	

_____ 1. A complete alteration of voltage or current in an alternating current circuit.

_____ 2. A safety device in an electric circuit that automatically shuts off the circuit when it becomes overloaded.

_____ 3. The ratio of true power passing through an electric current to the product of the voltage and amperage in the circuit.

_____ 4. An expression representing an electrical connection to earth or a large conductor that is at the earth's potential or neutral voltage.

_____ 5. The electrical pressure available to cause a flow of current when an electric circuit is closed.

_____ 6. The strength of an electric current measured in amperes.

_____ 7. That property of a conductor or wire that opposes the passage of a current, thus causing electric energy to be transformed into heat.

_____ 8. A wire or conductor that can carry electric current.

_____ 9. A blue paste or liquid used to show a contact area. Used to determine if gate valve seats fit properly.

_____ 10. The electrical pressure available to cause a flow of current when an electric circuit is dead.

_____ 11. Electric current flowing in only one direction and essentially free from pulsation.

_____ 12. The unit used to measure current strength.

_____ 13. A substance that dissociates (separates) into two or more ions when it is dissolved in water.

- _____ 14. The condition that occurs when a valve is opened or closed very rapidly.
- _____ 15. In electricity, a substance, body, device, or wire that readily conducts or carries electric current.
- _____ 16. The unit of electrical resistance. The resistance of a conductor in which one volt produces a current of one ampere.
- _____ 17. A protective device having a strip or wire of fusible metal that, when placed in a circuit, will melt and break the electric circuit if heated too much.
- _____ 18. A very small, negatively charged particle that is practically weightless. The part of an atom that determines its chemical properties.
- _____ 19. A measurement of the amount of electrical charge carried by an electric current of 1 amp/second. Equal to 6.25×10^{18} electrons.
- _____ 20. Absorbing or attracting moisture from the air.
- _____ 21. The complete path of an electric current including the generating apparatus or other source.
- _____ 22. An open, vertical empty space between a drinking water supply and potentially contaminated water.
- _____ 23. The number of complete electromagnetic cycles or waves in one second of an electric or electronic circuit. Also called the frequency of the current.
- _____ 24. An instrument used for checking the insulation resistance on motors, feeders, etc.
- _____ 25. A movement or flow of electricity. Measured by the number of coulombs per second.
- _____ 26. A electric current that reverses its direction (positive/negative values) at regular intervals.

Answers

- | | | |
|------|-------|-------|
| 1. J | 10. Y | 19. H |
| 2. F | 11. K | 20. R |
| 3. V | 12. D | 21. E |
| 4. P | 13. L | 22. A |
| 5. M | 14. Z | 23. Q |
| 6. C | 15. G | 24. T |
| 7. X | 16. U | 25. I |
| 8. S | 17. O | 26. B |
| 9. W | 18. N | |

Section 3

Iron & Manganese




Iron and Manganese

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Objectives

- Limits and causes
- Sampling and testing
- Treatment

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Iron and Manganese

- Caused by water being in contact with soil and rocks and dissolving the iron and manganese
 - More prevalent in groundwater
- Iron
 - Symbolized by Fe
 - sMCL = 0.3 mg/L
- Manganese
 - Symbolized by Mn
 - sMCL = 0.05 mg/L

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Iron Bacteria

- Bacteria oxidizes the ferrous ion (Fe^{2+}) and manganous ion (Mn^{2+}) and reduce carbon dioxide to form an organic slime
- Form thick slimes (**ferric hydroxide**) on water mains
 - Rust colored -- iron
 - Black -- manganese
 - **Gallionella** – iron bacteria
- Variations in flow loosens slimes and cause dirty water and tastes & odors complaints
- Controlled by chlorination
- Only one cell of iron bacteria is needed to start an infestation in a well or distribution system



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Occurrence of Fe and Mn

- Reacts with dissolved oxygen to form insoluble compounds
 - Solids that cannot be dissolved
- Surface waters are generally free from both
 - Exception: Mn up to 1 mg/L or higher may be found in shallow reservoirs and may come and go several times a year
- Most commonly found in groundwater systems
- Iron bacteria found everywhere
 - Anywhere there is a combination of dissolved oxygen and dissolved iron

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Sampling and Testing of Iron & Manganese

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Sampling for Iron and Manganese

- Best place to look is household plumbing fixtures
 - Staining of plumbing fixtures indicates high levels of Fe & Mn
- Samples are difficult to collect
 - Particles of scale are dislodged when opening tap will enter sample
 - Scale can form on inside of sample bottle and be left behind when sample is poured out (acidification will prevent this)
- Collect samples from a plastic sample line located as close to the source (i.e. well) as possible
 - Open tap slowly
 - Allow water to flow 1 minute for each 10 feet of sample line

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Sampling for Iron and Manganese

- Test sample within 48 hours
 - If holding time will be longer, preserve sample with nitric acid
 - If visible rust or clay in sample, test sample right away
 - Acidifying the sample will dissolve the iron and give high results

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Analysis of Iron and Manganese

- Atomic absorption
 - Preferred method but expensive
- Colorimetric
 - Sufficiently accurate in most circumstances
 - Use either a spectrophotometer, a filter photometer, or a set of matched Nessler tubes with standards

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Analysis of Total Iron (CSUS)

- Colorimetric test procedure
 1. Measure 50 mL of sample into flask
 2. Add 2 mL concentrated HCl and 1 mL hydroxylamine solution
 3. Heat to boiling
 - Boil until volume is reduced to 20 mL
 - Cool to room temperature.
 4. Transfer into 100 mL flask
 5. Add 10 mL acetate buffer and 2 mL phenanthroline solution
 - Dilute to 100 mL
 6. Measure absorbance at 510 nm with spectrophotometer

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Analysis of Iron and Manganese (Hach)

- **Iron**
 - Hach's method has a detection range of 0.02 - 3.0 mg/L
 - Three-minute reaction period needs to take place before reading
- **Manganese**
 - Hach has 2 methods
 - High range
 - 0.2 - 20.0 mg/L
 - Low range
 - PAN method
 - 0.007 - 0.700 mg/L
 - Iron can be an interference if it is in excess of 5 mg/L
 - Allow 10-minute reaction period

**Make sure to use low
range; this sees down to
sMCL
(0.05 mg/L)**

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Analysis of Total Iron (Hach)

- Colorimetric test procedure
 1. Fill sample cell with 10 mL of sample
 2. Add 2 FerroVer Iron Reagent Powder Pillow to the sample cell
 - Swirl to mix
 3. Let sit for 3 minute reaction time
 - If iron is present, sample will turn orange
 - If sample contains rust, let sit for 5 minutes
 4. Zero instrument with blank (sample)
 5. Read results given by spectrophotometer at 510 nm

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Analysis of Total Iron (Hach)

- Summary of method:
 - FerroVer Iron converts all soluble iron and most insoluble iron in the sample to soluble ferrous iron. The ferrous iron reacts with the phenanthroline indicator in the reagent to form an orange color in proportion to the iron concentration.

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Analysis of Manganese (CSUS)

- Colorimetric test procedure
 - 1. Measure 100 mL of sample into flask
 - Flash should be marked at the 90 mL level
 - 2. Add 5 mL of special reagent and 1 drop H_2O_2
 - 3. Concentrate to 90 mL by boiling
 - Add 1 gram ammonium persulfate
 - Cool immediately under water tap
 - 4. Dilute to 100 mL
 - 5. Measure the absorbance at 525 nm with a spectrophotometer

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Analysis of Manganese (Hach)

- Colorimetric test procedure
 - 1. Pour 10 mL of sample into sample cell
 - 2. Add contents of one Ascorbic Acid Powder Pillow to each cell
 - 3. Stopper and invert cell to dissolve the powder
 - 4. Add 12 drops of Alkaline-Cyanide Reagent Solution
 - Swirl to mix
 - 5. Add 12 drops of PAN Indicator Solution, 0.1%
 - Swirl to mix
 - An orange color will appear if manganese is present
 - 6. Let sit for 2-minute reaction time
 - 7. Read results given by spectrophotometer at 560 nm

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Analysis of Manganese (Hach)

- Summary of method
 - The PAN method is a highly sensitive and rapid procedure for detecting low levels of manganese. An ascorbic acid reagent is used initially to reduce all oxidized forms of manganese to Mn^{2+} . An alkaline-cyanide reagent is added to mask any potential interferences. PAN Indicator is then added to combine with the Mn^{2+} to form an orange-colored complex.

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Iron and Manganese Treatment



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Iron and Manganese Treatment

- Chemical treatment
- Ion Exchange
- Oxidation to insoluble forms followed by filtration
 - Aeration
 - Chlorine
 - Permanganate

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Phosphate Treatment

- Can be used if Mn < 0.3 mg/L and Fe < 0.1 mg/L
- Three types of polyphosphates
 - Pyrophosphate
 - Tripolyphosphate
 - Metaphosphate
- Polyphosphate delays precipitation of oxidized Mn to minimize scale build up on pipe walls
- Chlorine must be fed too to prevent the growth of iron bacteria
- Treatment most effective when added upstream of chlorine

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Phosphate Treatment

- Never feed chlorine upstream of polyphosphate because it will oxidize the Fe and Mn and form insoluble precipitates too soon
- Solutions with > 60mg/L may be very viscous (thick)
- Do not use a solution over 48 hours old
 - Polyphosphates react with water to form orthophosphates which are not as effective

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Remedial Action – Alternate Source

- Cost of iron and removal plant will be same as or more than drilling a new well
- Investigate alternate source of water free of iron and manganese
 - Sample nearby private wells
 - Talk to well drillers in the area
 - Talk with state engineers and regulators

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Removal by Ion Exchange

- If no dissolved oxygen is present, iron and manganese can be removed while softening
- If water to be treated contains any dissolved oxygen, rust and insoluble manganese dioxide will form, fouling the resin
- Advantage – plant requires little attention
- Disadvantages – danger of fouling resin and high initial cost
- Operate as close to design flows as possible
- Monitor treated water on a daily basis
 - If Fe and Mn start to appear in treated water, it is time to regenerate the resin
 - Make a brine of 0.01 lb of sodium bisulfite per gallon

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Oxidation by Aeration

- Iron and manganese can be oxidized to insoluble form by aeration
 - Mn oxidation by aeration is very slow and therefore rarely done
- Must maintain flow
 - Too high – not enough reaction time
- Reaction basin follows aeration
 - Allows time for oxidation reaction to take place
 - Minimum amount of detention time is 20 minutes (Design Criteria 4.7.1(b))
- After reaction, insoluble iron (ferric hydroxide) is removed by sedimentation or filtration
 - Maximum filtration rate is 3 gpm/ft² (Design Criteria 4.7.1 (c))

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Oxidation by Aeration

- Reaction Times

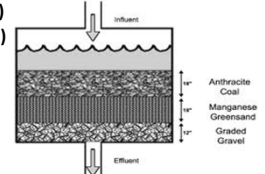
↑ pH	↓ Time
↓ organic substances	↑ Time
↓ temperature	↑ Time
- Advantage – no chemicals required
- Disadvantages – small changes in raw water may affect the pH soluble organics level and slow the oxidation rates
 - This can reduce the plant capacity

Oxidation with Chlorine

- Chlorine will oxidize both iron and manganese into an insoluble form
- The higher the residual, the faster the reaction time
- Treatment process
 - Raise residual up to high levels
 - Filter out insoluble particles
 - Lower chlorine level with dechlorinating agent
- Do not use this method on water with high organics
- Be sure not to add too much dechlorinating agent and bring the residual too low

Oxidation with Permanganate

- Dose must be exact
 - Too little – Mn will not oxidize
 - Too much – pink water goes to distribution system
- Often used in the form of Zeolite or a manganese greensand filter
- Manganese greensand filters can operate in three modes
 - Continuous regeneration (CR)**
 - Intermittent regeneration (IR)**
 - Catalytic regeneration**



Manganese Greensand Filters



Conventional vs Manganese Greensand

- Greensand is finer than filter sand
- Filtration rate is slower
 - 2-5 gpm/ft²
- Backwash rate is lower
 - 12 gpm/ft² for greensand vs. 15 gpm/ft² for conventional
- Manganese greensand filter can remove up to 95% of both Fe and Mn

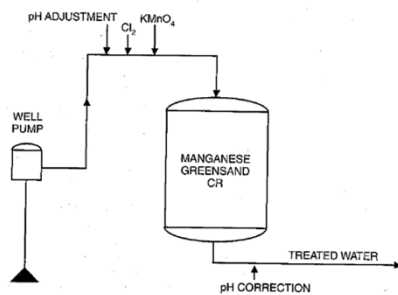
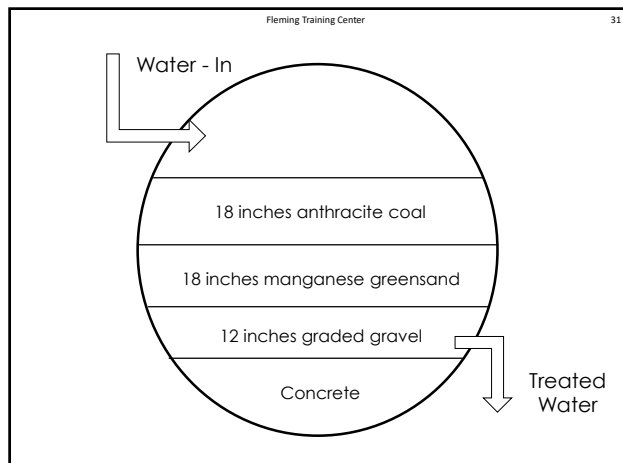


Fig. 12.5 Typical flow diagram of a continuous regeneration (CR) greensand process
(Permission of Hungerford & Terry, Inc.)

Equipment

- Filter with special filtering media
 - Greensand
 - Anthracite coal
 - Minimum of 6 inches - Design Criteria 4.7.3 (c)
- Continuous potassium permanganate fed prior to filter
- Filter must be able to be backwashed with air
- Filter must be able to be backwashed with permanganate solution for regeneration
- Various sampling points on either side of filter



Restrictions

- Maximum Fe concentration = 10 mg/L
- Maximum Mn concentrations = 5 mg/L
- Minimum pH = 6.2
 - For continuously regenerated (CR) manganese greensand process
- Sufficient detention time
 - Must give enough time for chemicals to react

Backwashing

- Filter must be backwashed to remove filtered particulates
 - When head loss reaches 10 psi
 - or
 - After treating a predetermined number of gallons
- Air wash is used for plants with high levels of manganese
 - Helps separate grains from the sticky manganese hydroxide oxidation products
 - Agitation keeps filter media in a free, loose, fluid condition

Greensand Regeneration

2 methods to regenerate greensand

- Method 1 – Intermittent Regeneration (IR)
 - Shut down and pour 5% potassium permanganate solution into the filters. Let sit for 24 hours
 - Back wash filters to flush excess KMnO_4

Greensand Regeneration

- Method 2 – Continuous Regeneration (CR)
 - Increase KMnO_4 dosage until pink water flows out of greensand media. Then decrease KMnO_4 until water is a slight pink color before the filter. If there is still pink water after filtration, keep decreasing KMnO_4 dose until no pink water is present in the filtrate.
 - Pink color is the best indicator that the greensand is regenerated or recharged
 - Be careful not to lower the permanganate level too far
 - Too little permanganate will allow iron and manganese to enter the distribution system

Continuous Regeneration (CR)

- Feed potassium permanganate prior to Mn greensand filter
- Permanganate will be reduced to manganese oxide
- Manganese oxides precipitate onto the greensand grains
- Continuous regeneration is achieved

CR / IR Troubleshooting		
Problem	Cause	Solution
Filter effluent clear, iron low, manganese higher than raw water	Manganese being leached from greensand grains	Increase frequency of regeneration
	Bed insufficiently regenerated	Regenerate bed with 0.5 oz/ft ³ of KMnO ₄ . Make sure proper influent chemicals are being continuously fed

TN

CR / IR Troubleshooting		
Problem	Cause	Solution
Filter effluent turbid with yellow to brownish color. Iron and manganese high.	Too much alkali being fed ahead of filter.	Reduce alkali feed. Keep influent pH 6.2-6.5.
	Polyphosphate being fed ahead of filter.	Discontinue polyphosphate feed. Check bed for mounds, pockets and channeling. Back wash.
	Iron organically bound: reactions with oxidizing agent produce a non-filterable colloid.	Feed alum or other coagulant prior to filter.

TN

CR / IR Troubleshooting		
Problem	Cause	Solution
Excessive pressure drop across bed immediately after backwashing.	Accumulation of greensand fines at surface of bed.	Scrape after backwashing, or if necessary, replace bed.
	Backwash rate too low.	Increase backwash rate to 10-12 gpm/ft ² .
	Filter bed cemented.	Break up cemented areas with air-water wash combination.
	Well throwing fine sand, silt, and colloidal clay.	Check well supply after pump start up. Allow well to pump overboard at start of pumping cycle.

TN

CR / IR Troubleshooting		
Problem	Cause	Solution
On multiple unit installation, water quality good on some units, bad on others.	Unequal distribution of pre-feed chemicals.	Inject chemical at a point where thorough mixing of chemicals with raw water occurs before diversion to the various filters

Continuous Regeneration (CR) Troubleshooting		
Problem	Cause	Solution
Iron breakthrough before recommended maximum change of pressure of 10 psi is reached.	Some iron waters filter in depth and do not build up head loss.	Backwash should be initiated by total number of gallons treated rather than by head loss. Use ΔP as a back up to prevent exceeding ΔP of 10 psi.
Faint pink color in filter effluent.	Permanganate feed rate is too high.	Operate filter 1-2 hours with KMnO ₄ feed off. Then reset feeder at slightly lower setting.

Continuous Regeneration (CR) Troubleshooting		
Problem	Cause	Solution
Low capacity.	Manganese oxide coating stripped from greensand grains due to insufficient regeneration. May be especially troublesome with high sulfide waters.	Increase frequency of regeneration. Pre-feed Cl ₂ with sulfide waters. Replace bed if required.
	Manganese greensand heavily iron-fouled.	Use CR method with dual-media anthracite/manganese greensand bed to prevent iron fouling.
	Excessive grain growth due to high manganese oxide buildup.	Increase frequency of regeneration. Bed replacement may eventually be required.

TN

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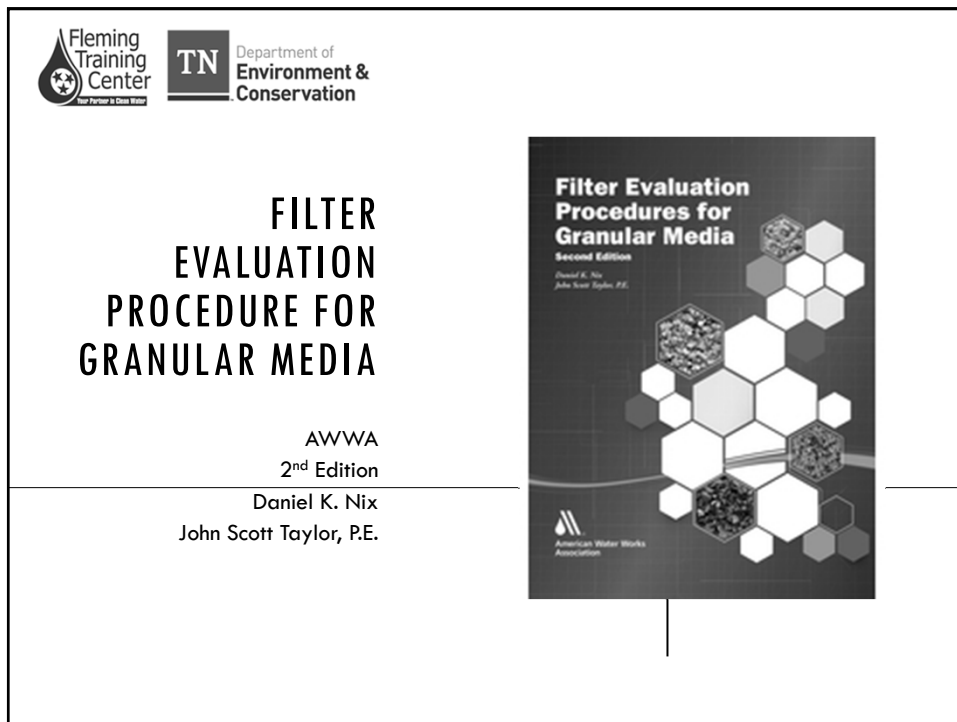
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Daily Testing

- Iron and manganese
 - Indicates that plant is operating at a level that meet state water quality requirements
- pH
 - Important due to relation between pH and corrosivity of the water
 - Needs to stay between 6.2 and 6.8 for effective Fe and Mn removal by the CR process
- Chlorine residual

Section 4

Filter Evaluation



OBJECTIVES

FILTRATION

- A physical process of removing suspended particles from a matrix (water) by passing through a *medium* that is permeable to the matrix but not the suspended solids
- No matter the media or configuration used, goal is same: removal of solid particles from a water
- Integral part of multiple-barrier approach
- Filters should be treated as engineered mechanical systems subject to preventative maintenance

FILTRATION REGULATIONS

- Safe Drinking Water Act (SDWA) passed in 1974
- Interim Primary Drinking Water regulations effective in 1977 set a maximum monthly average turbidity of 1.0 NTU
- Surface Water Treatment Rule (SWTR) issued in 1991
 - 95% of monthly 4-hr measurements must be at or below 0.5 NTU
 - Designed address *Giardia lamblia* contamination
- Interim Enhanced Surface Water Treatment Rule (IESWTR) issued 1998
 - 95% of monthly 4-hr measurements must be at or below 0.3 NTU
 - Requires filters out of compliance to be evaluated
 - Filter profile; Self-assessment; Comprehensive performance evaluation
- Designed to address *Cryptosporidium parvum* contamination

<p style="text-align: center;">LEVELS EXCEEDED</p>	<p>Depending on the exceedance level, the system must:</p> <ul style="list-style-type: none"> ▪ Produce a filter profile ▪ Conduct a self-assessment and/or ▪ Must arrange for the conduct of a comprehensive performance evaluation by the State or a 3rd party approved by the State <p style="text-align: right;">5</p>
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TENNESSEE PUBLIC WATER SYSTEMS 0400-45-01-.31(4)(c)

1. For systems using conventional filtration or direct filtration, the turbidity level of representative samples of a system's filtered water must be less than or equal to 0.3 NTU in at least 95 percent of the measurements taken each month, measured as specified in subparagraphs (5)(a) and (c) of this rule.
2. The turbidity level of representative samples of a system's filtered water must at no time exceed 1 NTU, measured as specified in subparagraphs (5)(a) and (c) of this rule.

TENNESSEE PUBLIC WATER SYSTEMS

0400-45-01-.31(5)(c)

1. Turbidity as required by paragraph (4) of this rule must be continuously measured and recorded on representative samples of the system's combined filtered water while the system serves water to the public. The highest turbidity value obtained during each four-hour period must be reported....
2. The residual disinfectant concentration of the water entering the distribution system must be monitored continuously, and the lowest value must be recorded each day. If there is a failure in the continuous monitoring equipment, grab sampling every four hours may be conducted in lieu of continuous monitoring, but for no more than five working days following the failure of the equipment....

TENNESSEE PUBLIC WATER SYSTEMS

0400-45-01-.31(5)(c)

4. ...a subpart H system serving 10,000 or more persons using conventional filtration treatment or direct filtration must conduct continuous monitoring of turbidity for each individual filter... and must calibrate turbidimeters... Systems must record the results of individual filter monitoring every 15 minutes...
5. If there is a failure in the continuous turbidity monitoring equipment, the system must conduct grab sampling every four hours in lieu of continuous monitoring until the turbidimeter is repaired and back on-line. A system has a maximum of five working days after failure to repair the equipment or it is in violation.

TENNESSEE PUBLIC WATER SYSTEMS

0400-45-01-.31(6)(b)(4)(ii)

I. For any individual filter that has a measured turbidity level of greater than 1.0 NTU in two consecutive measurements taken 15 minutes apart, the system must report the filter number, the turbidity measurement, and the date(s) on which the exceedance occurred. In addition, the system must either produce a **filter profile** for the filter within 7 days of the exceedance (if the system is not able to identify an obvious reason for the abnormal filter performance) and report that the profile has been produced or report the obvious reason for the exceedance.

TENNESSEE PUBLIC WATER SYSTEMS

0400-45-01-.31(6)(b)(4)(ii)

II. For any individual filter that has a measured turbidity level of greater than 0.5 NTU in two consecutive measurements taken 15 minutes apart at the end of the first four hours of continuous filter operation after the filter has been backwashed or otherwise taken offline, the system must report the filter number, the turbidity, and the date(s) on which the exceedance occurred. In addition, the system must either produce a **filter profile** for the filter within 7 days of the exceedance (if the system is not able to identify an obvious reason for the abnormal filter performance) and report that the profile has been produced or report the obvious reason for the exceedance.

FILTER PROFILE REPORT FOR INDIVIDUAL FILTERS
FOR PUBLIC WATER SYSTEMS THAT ARE USING SURFACE WATER SOURCES OR GROUND WATER SOURCES UNDER THE INFLUENCE OF SURFACE WATER THAT ARE REQUIRED TO CONDUCT ADDITIONAL INDIVIDUAL FILTER MONITORING

PUBLIC WATER SYSTEM NAME: TCEG WIS PLANT NAME OR NUMBER: FWP's Water Treatment Plant
PWS ID No.: 1234567 Month: February Year: 2002

OBSOLETE REASONS			
FILTER NO.: <u>1</u>	FILTER NO.: <u>2</u>	FILTER NO.: <u>3</u>	
DATE: <u>02-04-02</u>	DATE: <u>02-04-02</u>	DATE: <u>02-04-02</u>	
TIME: <u>10:00 AM</u>	TIME: <u>11:00 AM</u>	TIME: <u>11:25 AM</u>	
DURATION: <u>15.00</u>	DURATION: <u>15.00</u>	DURATION: <u>15.00</u>	
TURBIDITY: <u>1.32</u>	TURBIDITY: <u>2.87</u>	TURBIDITY: <u>1.58</u>	
OBSOLETE REASONS (Check all that apply):			
NONE IDENTIFIED - A Filter Profile must be submitted <input type="checkbox"/> (See Profile No. <u>1</u>) <input type="checkbox"/> (See Profile No. <u>2</u>) <input type="checkbox"/> (See Profile No. <u>3</u>)			
Filter Problems			
Post-Backwash Turbidity Spike	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Prolonged Filter Run Time	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Excessive Filter-Loading Rate	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rate-of-Flow Control Valve Failure	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Media Defects (insufficient depth, mudballs, etc.)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Inadequate Surface Wash or Backwash Facilities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Backwash Artifact	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Turbidimeter Errors			
Incorrect Calibration	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Air Bubbles	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Obstruction	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Chemical Feed Equipment Failure			
Coagulant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Coagulant Aid	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Filter Aid	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Filter Run Water Quality	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Other Major Unit Process Failure/Maintenance Activities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Specify: _____			

OBSOLETE REASONS			
FILTER NO.: <u>4</u>	FILTER NO.: <u>5</u>	FILTER NO.: <u>6</u>	
DATE: <u>02-13-02</u>	DATE: <u>02-13-02</u>	DATE: <u>02-13-02</u>	
TIME: <u>2:15 PM</u>	TIME: <u>2:15 PM</u>	TIME: <u>2:15 PM</u>	
DURATION: <u>15.00</u>	DURATION: <u>15.00</u>	DURATION: <u>15.00</u>	
TURBIDITY: <u>1.32</u>	TURBIDITY: <u>1.32</u>	TURBIDITY: <u>1.32</u>	
OBSOLETE REASONS (Check all that apply):			
NONE IDENTIFIED - A Filter Profile must be submitted <input type="checkbox"/> (See Profile No. <u>1</u>) <input type="checkbox"/> (See Profile No. <u>2</u>) <input type="checkbox"/> (See Profile No. <u>3</u>)			
Filter Problems			
Post-Backwash Turbidity Spike	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Prolonged Filter Run Time	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Excessive Filter-Loading Rate	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rate-of-Flow Control Valve Failure	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Media Defects (insufficient depth, mudballs, etc.)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Inadequate Surface Wash or Backwash Facilities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Backwash Artifact	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Turbidimeter Errors			
Incorrect Calibration	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Air Bubbles	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Obstruction	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Chemical Feed Equipment Failure			
Coagulant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Coagulant Aid	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Filter Aid	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Filter Run Water Quality	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Other Major Unit Process Failure/Maintenance Activities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Specify: _____			

SUBMITTED BY: Hardy Worker Certificate No. and Order: 123-45-6789, BSW Date: 24-Feb-02
TDEC - 10276 (10-02-00) PAGE 1 PPR

TENNESSEE PUBLIC WATER SYSTEMS 0400-45-01-.31(6)(b)(4)(ii)

III. For any individual filter that has a measured turbidity level of greater than 1.0 NTU in two consecutive measurements taken 15 minutes apart at any time in each of three consecutive months, the system must report the filter number, the turbidity measurement, and the date(s) on which the exceedance occurred. In addition, the system must conduct a **self-assessment** of the filter within 14 days of the exceedance and report that the self-assessment was conducted. The self assessment must consist of at least the following components: assessment of filter performance; development of a filter profile; identification and prioritization of factors limiting filter performance; assessment of the applicability of corrections; and preparation of a filter self-assessment report.

FILTER ASSESSMENT REPORT FOR INDIVIDUAL FILTERS
FOR PUBLIC WATER SYSTEMS THAT ARE USING SURFACE WATER SOURCES OR GROUND WATER SOURCES UNDER THE INFLUENCE OF SURFACE WATER THAT ARE REQUIRED TO CONDUCT AN INDIVIDUAL FILTER ASSESSMENT

PUBLIC WATER SYSTEM NAME: _____ PLANT NAME OR NUMBER: _____
 FILTER NUMBER: _____
 PWS ID No.: _____

DESIGN SPECIFICATIONS						
FILTER TYPE	OPERATING MODE					
MEDIA BED DIMENSIONS	Diameter (ft)	Length (ft)	Width (ft)	Surface Area (ft ²)	Freeboard (ft)	Max Head Loss (ft)
MEDIA TYPE	Material	Depth (inches)	Min. Size (mm)	Max. Size (mm)	UC	Specific Gravity
MEDIA SPEC	Layer 1 Material					
	Layer 2 Material					
	Layer 3 Material					
	Layer 4 Material					
TOTAL DEPTH (inches)						
L/D RATIO						
UNDERDRAIN TYPE	No. of Grades	Min. Size (in)	Max. Size (in)	Total Depth (in)		
SUPPORT GRAVEL						
TROUGH						
Number						
Separation (inches)						
Regulatory Size	Design	Typical	During Backwash	Maximum	App'd Exception	
FILTER FLOW RATE (gpm)						
LOADING RATE (gpm/ft²)						
BW FLOW RATE (gpm)						
BW LOADING RATE (gpm/ft²)						
FILTER INFLUENT	Source	Controller	Meter	Turbidometer	LONG	
FILTER EFFLUENT						
BACKWASH WATER						
ADDITIONAL REMARKS:						

OPERATING PROCEDURES						
CALIBRATION	Flow Meter	Backwash Meter	Mech. ROPC	NTU (Primary)	NTU (Secondary)	
Method						
Frequency						
Date of Last						
BACKWASH	Turbidity (NTU)	LOH (ft)	Run Time (hr)	Run Volume (gal)	Filtration Rate	
Criteria						
Monitoring Interval						
WRITTEN LOGS						
Plant Start-up						
Filter Start-up						
Plant Shutdown						
Filter Shutdown						
Filter Backwash						
Filter Inspection						
ADDITIONAL REMARKS:						

I certify that I am familiar with the information contained in this report and that, to the best of my knowledge, the information is true, complete, and accurate.

Operator's Signature: _____ Date: _____
 Operator's Name (printed): _____
 Certificate No. and Class: _____

Submit Report to TCEQ/PERM Division (Public Drinking Water Section/NO-155), ATTN: Monthly Reports, P.O. Box 13087, Austin, TX 78711-3087
 The report is due the 10th of the following month

TCEQ - 10277 (10-02-00) PAGE 1 Filter Assessment Report

FILTER ASSESSMENT REPORT FOR INDIVIDUAL FILTERS
FOR PUBLIC WATER SYSTEMS THAT ARE USING SURFACE WATER SOURCES OR GROUND WATER SOURCES UNDER THE INFLUENCE OF SURFACE WATER THAT ARE REQUIRED TO CONDUCT AN INDIVIDUAL FILTER ASSESSMENT

PUBLIC WATER SYSTEM NAME: _____ PLANT NAME OR NUMBER: _____
 FILTER NUMBER: _____
 PWS ID No.: _____

CURRENT CONDITIONS						
DATE	TIME	TURBIDITY (NTU)	LOH (ft)	FLOW RATE (gpm)	RUN TIME (hr)	RUN VOLUME (gal)
PHYSICAL CONDITION						
Wash						
Troughs						
Suppl. Backwash						
Flow Meter						
ROPC						
Flow Control Valve						
Turbidometer						
LONG						
ADDITIONAL REMARKS:						

MEDIA SURFACE CONDITIONS						
	Before BW	After BW		Before BW	After BW	
MOUNDS	Number		RETRACTION	Number		
Length (inches)			Length (inches)			
Width (inches)			Width (inches)			
Height (inches)			Depth (inches)			
DEPRESSIONS	Number		CRACKS	Number		
Length (inches)			Length (inches)			
Width (inches)			Width (inches)			
Depth (inches)			Depth (inches)			
ACCUMULATED FLOC	Thickness (inches)		MUDBALLS	No. per ft ²		
Distribution			Size (inches)			
ADDITIONAL REMARKS:						

BACKWASH CONDITIONS						
BW FLOW RATE (gpm)						
RISE RATE (inches/min)						
LOADING RATE (gpm/ft ²)						
DURATION (minutes)						
TOTAL VOLUME (gallons)						
TROUGH						
Leakiness						
Flooding						
SUPPL. BACKWASH						
Operator (minutes)						
Effectiveness						
JETTING						
No. of Jets						
Severity						
BW WATER DISTRIBUTION						
SPENT BWW TURBIDITY						
EXPANSION (inches)						
EXPANSION (percent)						
YIELD (percent)						
ADDITIONAL REMARKS:						

Submitted by: _____ Date: _____

TCEQ - 10277 (10-02-00) PAGE 2 Filter Assessment Report

FILTER ASSESSMENT REPORT FOR INDIVIDUAL FILTERS <small>FOR PUBLIC WATER SYSTEMS THAT ARE USING SURFACE WATER SOURCES OR GROUND WATER SOURCES UNDER THE INFLUENCE OF SURFACE WATER THAT ARE REQUIRED TO CONDUCT AN INDIVIDUAL FILTER ASSESSMENT</small>						
PUBLIC WATER SYSTEM NAME: _____		PLANT NAME OR NUMBER: _____				
PWS ID No.: _____		FILTER NUMBER: _____				
NUMBER OF SITES MEDIA Max. Thickness (inches) _____ Min. Thickness (inches) _____ Typ. Thickness (inches) _____ SUPPORT MATERIAL Max. Elevation _____ Min. Elevation _____ Typ. Elevation _____		FILTER PROBE ADDITIONAL REMARKS: _____ _____ _____				
FILTER EXCAVATION						
	REFERENCE	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6
SITE CHARACTERISTIC	Normal					
LAYER 1 (Top Layer)						
INTERFACE 1						
LAYER 2						
INTERFACE 2						
LAYER 3						
INTERFACE 3						
LAYER 4						
MUDBALLS						
Max. Size (inches)						
Min. Size (inches)						
Max. Depth (inches)						
	SITE 7	SITE 8	SITE 9	SITE 10	SITE 11	SITE 12
SITE CHARACTERISTIC						
LAYER 1 (Top Layer)						
INTERFACE 1						
LAYER 2						
INTERFACE 2						
LAYER 3						
INTERFACE 3						
LAYER 4						
MUDBALLS						
Max. Size (inches)						
Min. Size (inches)						
Max. Depth (inches)						
MEDIA CONDITION Sharpness _____ Encrustation _____ Uniformity _____		ADDITIONAL REMARKS: _____ _____ _____				
FILTER PROFILE ATTACHED? _____ <small>Note: A filter profile must be attached to this report.</small>		ADDITIONAL STUDIES ADDITIONAL REMARKS: _____ _____ _____				
PERCENT MUDBALLS Media Volume (cu) _____ Mudball Volume (cu) _____ % Mudballs _____						
CONCLUSIONS						
CONCLUSIONS: _____ _____ _____				CORRECTIVE ACTION PLAN ATTACHED? _____ WOULD YOU LIKE SOME TECHNICAL ASSISTANCE FROM THE TDEC? _____		
Submitted by: _____		Date: _____				
TCEQ - 10277 (10-02-00)		PAGE 3			Filter Assessment Report	

FILTER ASSESSMENT REPORT FOR INDIVIDUAL FILTERS <small>FOR PUBLIC WATER SYSTEMS THAT ARE USING SURFACE WATER SOURCES OR GROUND WATER SOURCES UNDER THE INFLUENCE OF SURFACE WATER THAT ARE REQUIRED TO CONDUCT AN INDIVIDUAL FILTER ASSESSMENT</small>	
PUBLIC WATER SYSTEM NAME: _____	
PWS ID No.: _____	
PLANT NAME OR NUMBER: _____	
FILTER NUMBER: _____	
FILTER SCHEMATIC	
PREPARE A SIMPLE FILTER SCHEMATIC SHOWING THE LOCATION OF BACKWASH WATER TROUGHS, OBSERVED ANOMOLIES, AND EXCAVATION SITES.	
Submitted by: _____	
Date: _____	
TCEQ - 10277 (10-02-00)	
PAGE 4	
Filter Assessment Report	

TENNESSEE PUBLIC WATER SYSTEMS

0400-45-01-.31(6)(b)(4)(ii)

IV. For any individual filter that has a measured turbidity level of greater than 2.0 NTU in two consecutive measurements taken 15 minutes apart at any time in each of two consecutive months, the system must report the filter number, the turbidity measurement, and the date(s) on which the exceedance occurred. In addition, the system must arrange for the conduct of a **comprehensive performance evaluation** by the Department or a third party approved by the Department no later than 30 days following the exceedance and have the evaluation completed and submitted to the Department no later than 90 days following the exceedance.

NOTES FROM FIELD OFFICE

- Having a filter exceedance is not a violation
- The violation occurs when the water system fails to submit the filter exceedance report or denote a filter exceedance on the Filter Performance Report
- It would be in the water system's best interest to go ahead and submit a filter exceedance report when in doubt rather than not submit a report at all

NOTES FROM FIELD OFFICE

- It may also be helpful for water systems to have a flow meter and be able to chart the flow of the effluent water going to the clear well against the turbidity

NOTES FROM FIELD OFFICE

- Also, the way the rules is written any measured turbidity level greater than 0.5 NTU in two consecutive readings 15 minutes apart requires a filter profile or obvious reason
- This means if someone knocks the turbidimeter and the reading is elevated above 0.5 NTU for fifteen minutes or longer, they will technically need to report the filter exceedance
- The obvious reason being someone bumped the turbidimeter



ORGANIZATION OF A FILTER EVALUATION PROGRAM

Chapter 2

FILTER EVALUATION PROGRAM

- If just one of the many factors required to make a filter work the way it was designed fails, a snowball effect will occur
- Filter evaluation is a large undertaking that creates an initial influx of huge amounts of data
- A continuous program that evaluates filters on a regular basis is most effective method of ensuring filter function

FILTER EVALUATION PROGRAM

- Think of filter evaluation as preventive maintenance for your filters
 - Unfortunately filters have been evaluated due to a problem or “run to fail” attitude
- Filter evaluations should not be a one-time event but part of an ongoing process

23

THE TEAM

- Should include:
 - Plant operators
 - Maintenance personnel
 - Laboratory technicians
 - Facility supervisor
 - Plant engineer



PRELIMINARY REVIEW

- Filter Design Review
- Filter History
- Water Quality Review
- Standard Operating Procedures Review

PRELIMINARY REVIEW

Preliminary Filter Design Review

- Media used
- Media depths for different grain sizes
- Designed backwash flow rates
- Effective size
- Uniformity coefficient
- Appropriated backwash bed expansion

PRELIMINARY REVIEW

Filter History

- Age of media
- Special cleaning performed and reason
- Results of cleaning
- Operational changes
 - Backwash flow rates
 - Media replacements
 - Filter run times

PRELIMINARY REVIEW

Water Quality Review

- Review current online turbidity data
 - Look for spikes and ask why
- Look at water produced by filter as well as the water being put through filter
 - If influent water quality is poor, the filters may be overloaded decreases its efficiency

PRELIMINARY REVIEW

Standard Operating Procedures Review

- Compare SOPs wash time and rates to original design parameters
- Filter termination criteria
 - Loss of head
 - Turbidity
 - Run time
- Evaluate past SOPs if possible
 - Try to determine reason for changes made

**WATER FROM SED BASINS

Good Rule of Thumb

- If your raw water turbidity is less than 10 NTU most of the time, then you should have about 1 NTU coming in from sedimentation basins
- If your raw water turbidity is greater than 10 NTU most of the time, then you should have about 2 NTU coming in from sedimentation basins

DATA ORGANIZATION



- Organization is utmost importance to program
- Each filter should have own file
 - Separated by year

EQUIPMENT NEEDED

- Before starting the filter evaluation you must:
 - Read carefully each procedure
 - Gather all necessary equipment



FILTER EVALUATION PROGRAM

Scheduling the Evaluation

- Filter evaluations should be performed annually

Writing the Report

- *Individual filter* format used when concentrating on one filter at a time
- *Procedure* format dedicated to procedure conducted with each filter's data shown together



SAFETY CONSIDERATIONS | Chapter 3

COMMUNICATIONS PROTOCOL

- Handheld Radio
- Visual Communications
 - Signals to convey a start and stop sequence
 - Signal to request help
 - Signal to indicate need more or less of something
 - Signal that conveys the instruction is confirmed or understood
 - Signal that indicates instruction was not understood



ENTERING A FILTER

- Remember, a filter bay is a considered a confined space, please take all necessary precautions before entering into filter bay
 - Use a ladder to enter the filter
 - Allow no more than one team member on the ladder at a time
 - Provide a source of forced air to the team members in the filter
 - Troughs can be walked down but not used to jump into the filter
 - No team member should enter the filter alone, practice the buddy system

ON THE FILTER SURFACE

1

Make sure filter is completely drained before entering

2

Never walk directly on filter media
• Use 2'x2' plywood boards

3

Watch for appurtenances around you that can be bumping hazards to the head

4

Do not move from one cell to the other by crawling under troughs or jumping

FLUIDIZING THE MEDIA

1. Install expanded metal grating over the wash-water drain piping
2. Do NOT fluidize filter bed with someone standing on surface of media
 - Team member must be properly attached to an emergency extraction harness and rope if must be in filter while media is fluidized
3. Minimum number team members to perform procedure: 3
 - Filter insertion member
 - Safety officer
 - Filter operations team member
4. All extraction ropes should be able to stop a falling person
5. Team member must know filter emergency shut-down procedure BEFORE starting evaluation process

PROTECTIVE EQUIPMENT	<div>Rubber boots</div> <div>Hard hat</div> <div>Safety rope or harness</div> <div>Ladder</div> <div>Ventilation equipment</div> <div>Expanded metal grating (if fluidizing filter bed)</div> <div>Buck and rope hoisting system</div> <div>Flashlight</div> <div>Radio/communication system</div>
---------------------------------	--

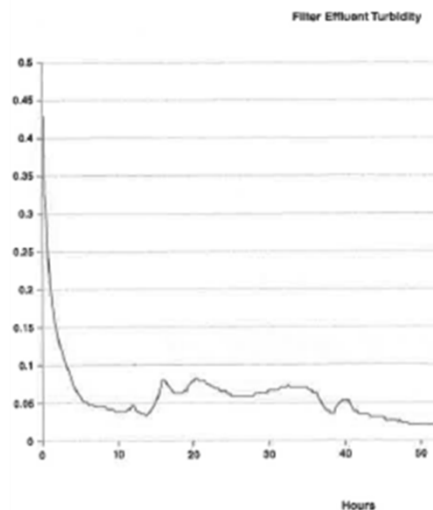


FILTER INDICES

Chapter 4

PERFORMANCE OVER TIME

- May use any combination of
 - Head loss
 - Effluent turbidity level
 - Elapsed run time
- Record length of time that filter is in operation between backwashes
 - Graph results including recorded turbidity and head loss levels



e 4-1 Performance over time

UNIT FILTER RUN VOLUME (UFRV)

- Used to compare the throughput of the filter under filtration rates
 - The volume of water processed through a filter in a single filter run between backwashes
- UFRV may stay same or increase due to higher filtration rate
- Record UFRV for each filter run; graph and watch for trends that could indicate the need for a filter evaluation

$$\text{UFRV, } \frac{\text{gal}}{\text{ft}^2} = \text{filtration rate, } \frac{\text{gpm}}{\text{ft}^2} \times \text{filter run time, hr} \times 60 \text{ min/hr}$$

- Calculate and graph UFRV for each filter run to see trends
 - UFRV < 5,000 gal/ft² = short filter run times
 - UFRV > 10,000 gal/ft² = better performance
 - UFRV > 15,000 gal/ft² = good performance

FILTER EFFICIENCY

$$\frac{R_e}{R_o} = \frac{UFRV - UBWV}{UFRV}$$

R_e = effective filtration rate (gpm/ft²)

R_o = operating filtration rate (gpm/ft²)

UFRV = unit filter run volume (gal/ft²)

UBWV = unit backwash volume (gal/ft²)

OR

Using the FTC formula book:

$$\text{Backwash Water, \%} = \frac{\text{Backwash Water, gal}}{\text{Water Filtered, gal}} \times 100\%$$

- Need:
 - Filter run time (hours)
 - Volume of water filtered
 - Operating filtration rate
 - Volume of backwash water used
- Acceptable ranges between 95-98%
 - Less than 95% is poor performance
- End number ($\frac{R_e}{R_o}$) provides a filter efficiency ratio

❖ Performance Note:

Filter performance will increase during the summer months and decrease during winter months. If the efficiency stays above 95%, there should not be a cause for concern.

L/d RATIO

- Ratio of bed depth (L) to the effective size of the media (d)
- Based on concept that equivalent L/d ratios will produce equal filtrate quality when filtering the same influent water at the same filtration rate
- If dual or multimedia design, determine ratio for each medium and add them together

L/d ≥ 1,000	for ordinary monosand or dual media beds
L/d ≥ 1,250	for tri-media or coarse monomedium beds
L/d ≥ 1,250-1500	for very coarse monomedium beds

❖ Performance Note:

If the desired filtered water turbidity is less than 0.1 NTU, and a polymer filter aids are not used, the L/d ratio should be increased by 15%.

L/d RATIO EXAMPLE

Is this an acceptable L/d Ratio for this filter?

	Media 1	Media 2	Media 3	Media 4
L = depth of filter in mm	406.4 mm (16 in.)	736.6 mm (29 in.)		
d = effective size of media	0.69	1.22		
L/d Ratio for media layer	589	604		
L/d Ratio for filter	1193			

YES

$L/d \geq 1,000$

for ordinary monosand or dual media beds



Department of
Environment &
Conservation

FILTER RUN HOUR ANALYSIS

Chapter 5

FILTER RUN HOUR ANALYSIS

Allows operator to see how many hours in a year the filters are operated

- Compares one filter to all the other filters in the facility

Shows if filter runs are being ended prematurely

- Reason for short filter run should be determined and addressed

PROCEDURE

Step 1.

Do monthly count and document the number of hours each filter was producing water



Step 2.

Total the annual filter run hours for each filter and graph



Step 3.

If annual graph shows discrepancies, use monthly totals to generate bar graphs to narrow down time frame

FILTER RUN ANALYSIS

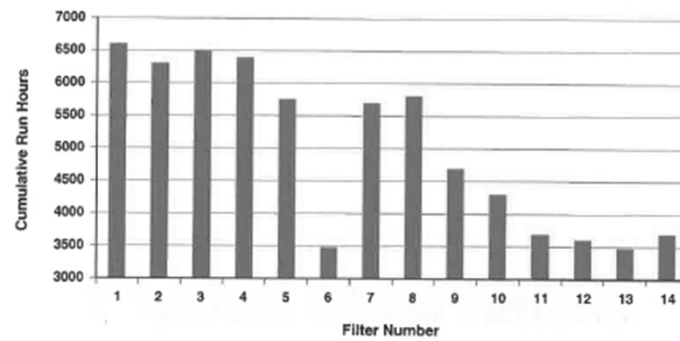


Figure 5-2 This is a run hour analysis of a "long filter corridor" indicating that the filters at the end of the corridor were not used as much as the filters at the beginning of the corridor. It also shows that Filter No. 6 was not as much as the filters on either side of it. This was due to a filter maintenance issue that had been overlooked.



PHYSICAL OBSERVATIONS

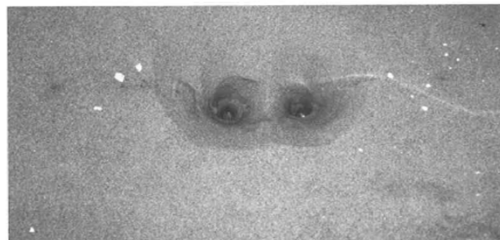
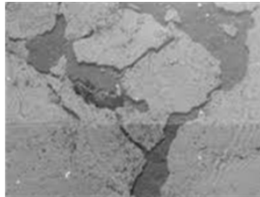
Chapter 6



PHYSICAL OBSERVATIONS

Observe surface of filter media as well as any appurtenances

- Cratering or mounding
- Mud or silt on filters
- Cracking or separating from wall
- Media depth
- Wash-water trough levelness
- Freeboard measurement

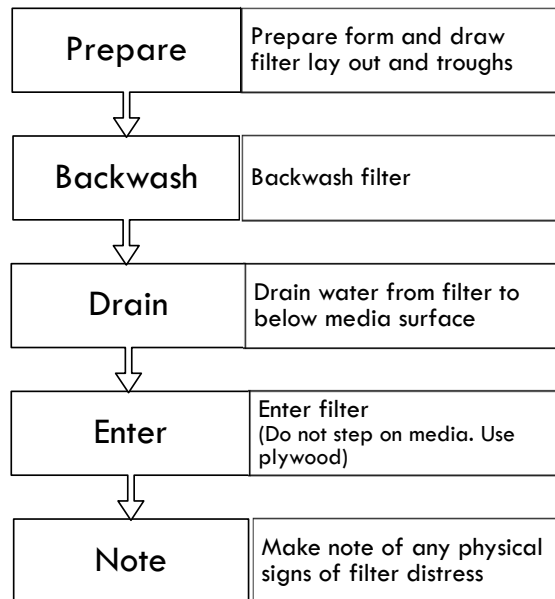


EQUIPMENT NEEDED

- Physical Observation Form
- 3'x3' plywood
- Electrical tape
- Punch rod
- Carpenter's level
- Measuring tape

Physical Observations Form

PROCEDURE



NOTING FILTER CONDITIONS

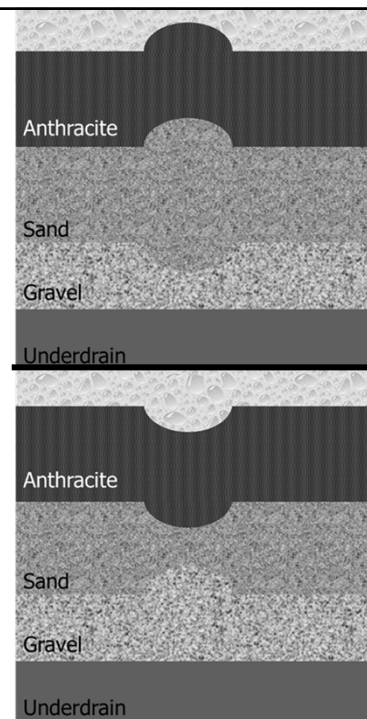
a. Mounding

- Any areas of media that are raised higher than the surrounding media
- Could indicate gravel layer disturbance



b. Craters

- Any areas of media that are lower than the surrounding media
- Could indicate gravel layer disturbance



NOTING FILTER CONDITIONS

c. Mud/silt



- Mud/silt/mudballs visible on surface indicate poor surface wash and more mudballs may exist deeper in media

d. Cracks



- Allows water to pass directly through the media without being filtered
- Indicates insufficient backwash



e. Sand separation from walls

- Media separating from walls
- Insufficient backwash rate

NOTING FILTER CONDITIONS

f. Algae

a

- All noticeable algae in a filter or filter appurtenances should be removed to prevent clogging media

g. Structural

X

- Structural defects in walls, troughs, or piping; chipping concrete; rusting iron rebar or walls
- Issues will continue to get worse if not corrected

h. Media in troughs

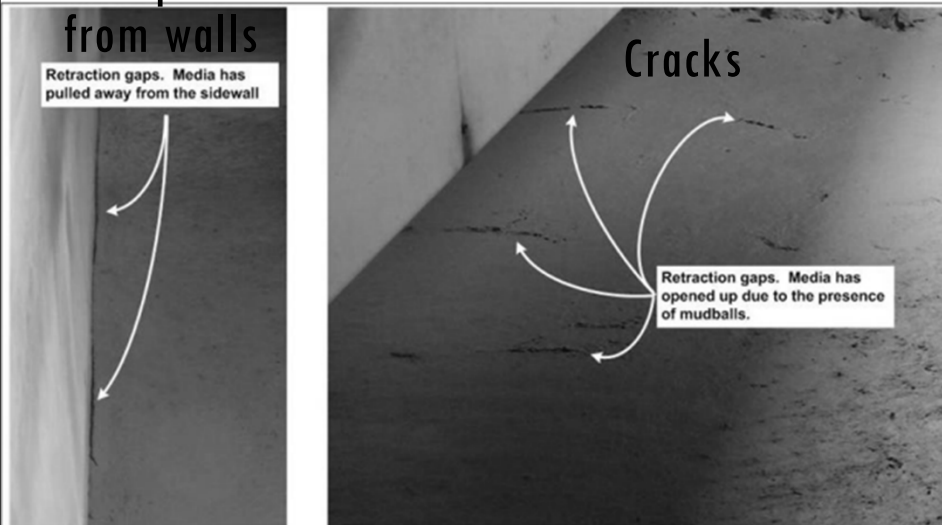
+

- Media in backwash water troughs indicates too high a backwash rate
- Note the type of media if more than one is present in filter

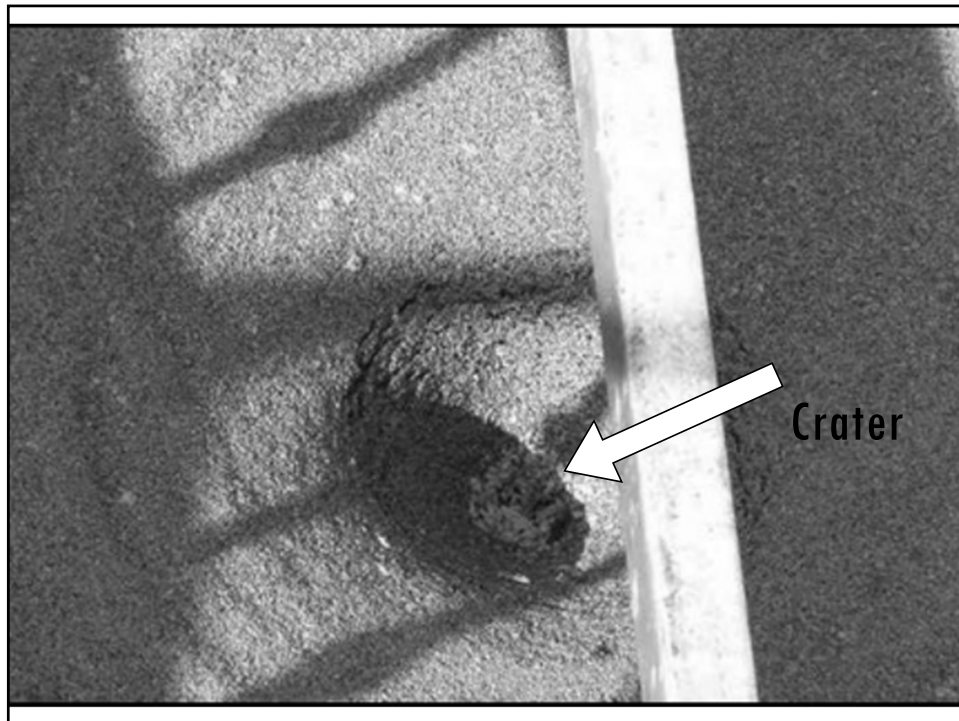
NOTING FILTER CONDITIONS

- i. Media depth
 - Using a punch rod, measure the media depth 5-6 times throughout the filter
 - Make note/measurement of where measurements were taken
- j. Levelness of wash-water troughs
 - Using a carpenter's level, at both ends of trough and in middle, check levelness
- LV
 - Across width of trough
 - Down length of both sides
 - Between adjacent troughs
 - Using water, observe if water passes over the troughs at same time
- k. Freeboard measurement
 - Distance from top of trough to top of media surface
 - Generally, 2 ft from media to bottom of trough is acceptable

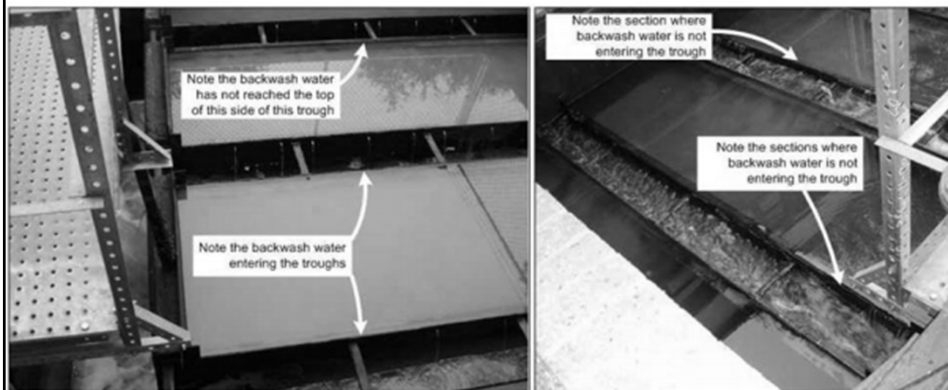
Sand separation

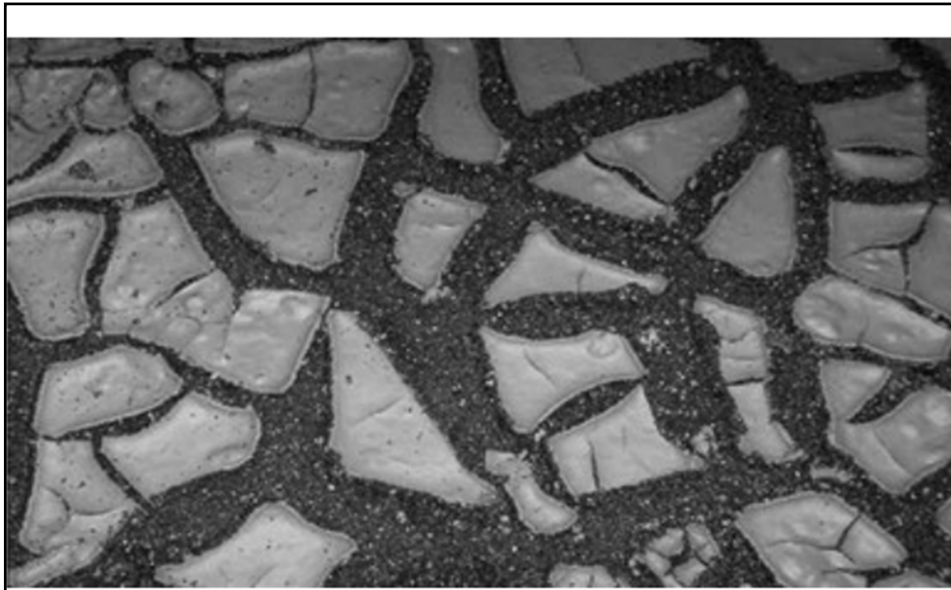


Note the appearance of the surface of the filter. The layer of congealed floc is an indication that the filter is operating in a "surface filtration" and not a "depth filtration" mode. These layers are commonly formed when there is a coagulant overfeed and/or poor sedimentation.



LEVELNESS OF WASH-WATER TROUGHS



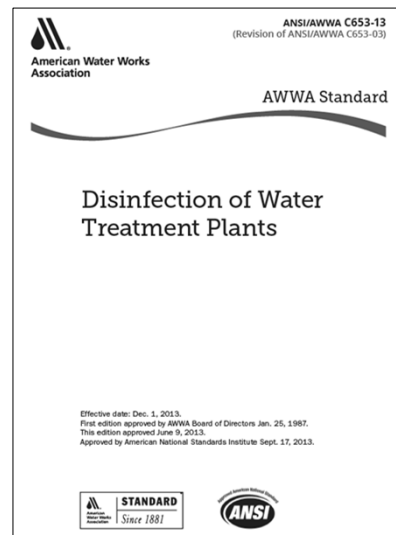


**Figure 39: Surface Accumulations: These really aren't cracks...
It's dried floc on top of a filter that was drained before backwashing**

Physical Observations Form																					
Date: <u>1-1-11</u>	Filter ID: <u>#12</u>																				
Team member: <u>DN</u>	Team member: <u>ST</u>																				
Team member: _____																					
Media Depth Measurements																					
Site #1: <u>36</u> inches	Site #2: <u>35.5</u> inches																				
Site #3: <u>36.2</u> inches	Site #4: <u>36</u> inches																				
Site #5: <u>37</u> inches	Site #6: <u>37</u> inches																				
Physical Observations (see diagram on reverse for Levels & Measurements)																					
<p>Comments: There is a large amount of algae along the NW wall and washwater trough.</p> <p>No structural defects.</p> <p>Mud has accumulated in 3 corners, with sand separation seen in SW corner.</p> <p>Crater is evident in center of filter and along the S wall.</p>																					
<table border="1"> <tr> <td>Mounting</td> <td><input checked="" type="checkbox"/></td> <td>Crater</td> <td><input checked="" type="checkbox"/></td> <td>Sand Separation</td> <td><input checked="" type="checkbox"/></td> </tr> <tr> <td>Media/Filter</td> <td><input checked="" type="checkbox"/></td> <td>Cracks</td> <td><input checked="" type="checkbox"/></td> <td>Algae</td> <td><input checked="" type="checkbox"/></td> </tr> <tr> <td>Structural</td> <td><input checked="" type="checkbox"/></td> <td>Media In Trough</td> <td><input checked="" type="checkbox"/></td> <td>Location</td> <td><input checked="" type="checkbox"/></td> </tr> </table>				Mounting	<input checked="" type="checkbox"/>	Crater	<input checked="" type="checkbox"/>	Sand Separation	<input checked="" type="checkbox"/>	Media/Filter	<input checked="" type="checkbox"/>	Cracks	<input checked="" type="checkbox"/>	Algae	<input checked="" type="checkbox"/>	Structural	<input checked="" type="checkbox"/>	Media In Trough	<input checked="" type="checkbox"/>	Location	<input checked="" type="checkbox"/>
Mounting	<input checked="" type="checkbox"/>	Crater	<input checked="" type="checkbox"/>	Sand Separation	<input checked="" type="checkbox"/>																
Media/Filter	<input checked="" type="checkbox"/>	Cracks	<input checked="" type="checkbox"/>	Algae	<input checked="" type="checkbox"/>																
Structural	<input checked="" type="checkbox"/>	Media In Trough	<input checked="" type="checkbox"/>	Location	<input checked="" type="checkbox"/>																

DISINFECTION

- Filter has been contaminated by those working on and in the filter media
 - Disinfection must take place before the filter is placed back into service
 - Follow AWWA Standard C653, Disinfection of Water Treatment Plants or the plant's pre-approved media-disinfection guidelines
- Granular activated carbon (GAC) cannot be disinfected, so special care should be used to protect against contamination



Department of
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BACKWASH OBSERVATIONS

Chapter 7

BACKWASH OBSERVATIONS

Should be performed by
evaluation team at least
once per year

Equipment needed:

- 2 team members
- Backwash Observation form

Backwash Observations Form

Date: _____ Filter ID: _____

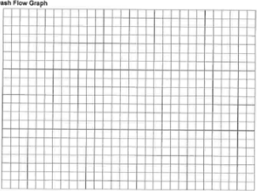
Team member: _____ Team member: _____

Team member: _____

Backwash Flow Rate		
1 minute	gpm	11 minutes
2 minutes	gpm	12 minutes
3 minutes	gpm	13 minutes
4 minutes	gpm	14 minutes
5 minutes	gpm	15 minutes
6 minutes	gpm	16 minutes
7 minutes	gpm	17 minutes
8 minutes	gpm	18 minutes
9 minutes	gpm	19 minutes
10 minutes	gpm	20 minutes
11 minutes	gpm	21 minutes
12 minutes	gpm	22 minutes
13 minutes	gpm	23 minutes
14 minutes	gpm	24 minutes
15 minutes	gpm	25 minutes
16 minutes	gpm	26 minutes
17 minutes	gpm	27 minutes
18 minutes	gpm	28 minutes
19 minutes	gpm	29 minutes
20 minutes	gpm	30 minutes

Backwash Water Temperature _____ °F Backwash Volume Used _____ gal

Backwash Flow Graph



Comments

Surface Wash ☐

Drop ☐

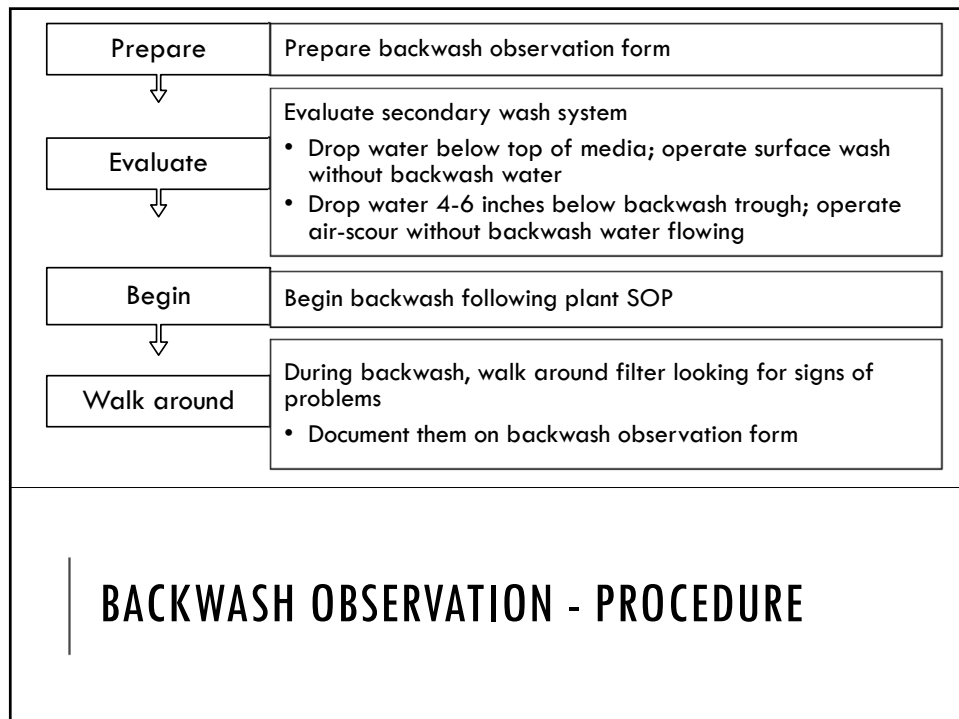
Boiling ☐

Reverse ☐

Operate Valve ☐

Sample ☐

View ☐



BACKWASH OBSERVATION

Walk around filter perimeter during backwash

- Media boiling



- Done at end of backwash because media must be in view
- Indicates filter issues below the surface

- Uneven distribution of backwash water



- Lack of media movement = decrease backwash flow rate
- This will lead to mudballs in filter

- Media carryover

- Media left in troughs after backwash



- Can indicate backwash water may be jetting under troughs; media may expand too close to bottom of trough; or backwash rate too high for filter

BACKWASH OBSERVATION

Walk around filter perimeter during backwash
cont'd

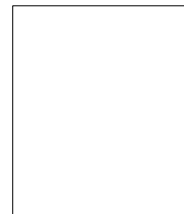
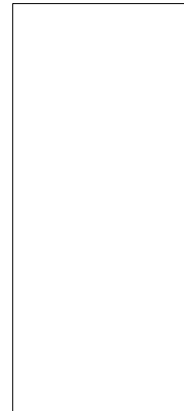
- Backwash trough capacity

- Troughs able to carry backwash water when working at max capacity

- 2-inch freeboard inside of trough (TN Design Criteria 4.2.1(f)(3))

- Make notes in comments sections of backwash observation form

- Note any mechanical system malfunctions



BACKWASH OBSERVATION

Interpretation of the Results

- Media boiling and uneven distribution = disruption in gravel support bed or failure of underdrain system
- Media carryover = too high backwash rate
- Surface wash or mechanical issues should be addressed by maintenance immediately

BACKWASH OBSERVATION FORM

Backwash Observations Form

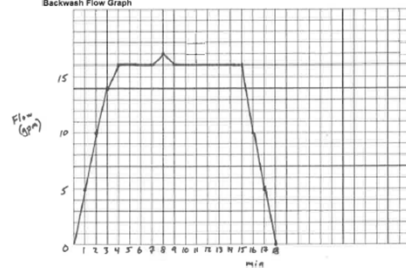
Date: 1-1-11 Filter ID: #2
 Team member: DJ Team member: ST
 Team member: _____

Backwash Flow Rate

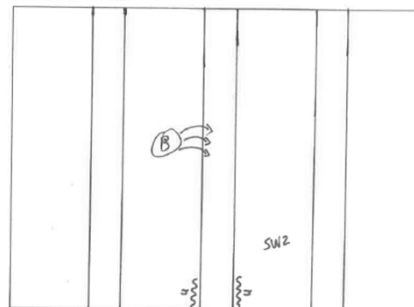
1 minute	5 gpm	11 minutes	12 gpm	21 minutes	gpm
2 minutes	10 gpm	12 minutes	12 gpm	22 minutes	gpm
3 minutes	10 gpm	13 minutes	12 gpm	23 minutes	gpm
4 minutes	12 gpm	14 minutes	12 gpm	24 minutes	gpm
5 minutes	12 gpm	15 minutes	12 gpm	25 minutes	gpm
6 minutes	12 gpm	16 minutes	10 gpm	26 minutes	gpm
7 minutes	12 gpm	17 minutes	8 gpm	27 minutes	gpm
8 minutes	12 gpm	18 minutes	0 gpm	28 minutes	gpm
9 minutes	12 gpm	19 minutes	gpm	29 minutes	gpm
10 minutes	12 gpm	20 minutes	gpm	30 minutes	gpm

Backwash Water Temperature 64 °F Backwash Volume Used 180,000 gal

Backwash Flow Graph



Backwash Observations



Comments: Surface Wash Arm #2 has several nozzles that are not working.

Large Boil in center of the filter with a lot of media carryover.

Uneven water in the center part of the filter along the S. wall.

Surface Wash	SW	Boiling	<input checked="" type="radio"/>	Uneven/No Air	<input checked="" type="radio"/>
Uneven Water	<input checked="" type="radio"/>	Carryover	<input checked="" type="radio"/>		



BACKWASH BED EXPANSION ANALYSIS

Chapter 8

BACKWASH BED EXPANSION

- Direct indication of backwash system efficiency
- Should have a bed expansion goal
 - At least 50% (TN Design Criteria 4.2.1(k)(1))
- Determined by
 - Filter media
 - Size
 - Gradation
 - Grain shape
 - Density
 - Water
 - Viscosity
 - Density
 - Temperature

Backwash Bed Expansion Analysis Form

Date _____	Filter ID _____			
Team member _____	Team member _____			
Team member _____				
Filter Measurements				
Depth of Filter Media: _____ inches				
Field Data				
Initial Level: _____ inches	Final Level: _____ inches			
Calculations				
Initial Level in inches	Final Level in inches	=	Change of Level in inches	
Change of Level in inches	Depth of Media in inches	=	Percent Expansion	
Decimal Equivalent	X	100	=	Percent Bed Expansion
Comments:				

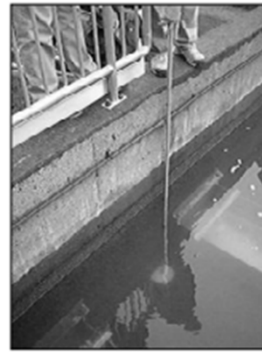
RULER GAUGE METHOD (SECCHI DISK)

- Before backwashing, lower the ruler gauge into the filter
- When ruler reaches media surface, record initial reading
- Once backwash begins, lower ruler back into filter to media surface
- Record final reading
- Calculation

$$L_i - L_f = L_{\Delta}$$

Initial – final = change

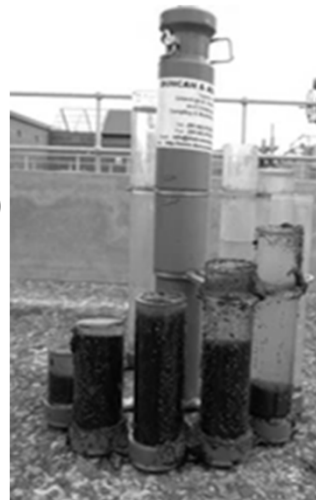
$$\left(\frac{L_{\Delta}}{D_{original}} \right) \times 100 = \% \text{ bed expansion}$$



TUBE SAMPLER METHOD

- Lower tube sampler onto filter surface and secure in place
- Begin backwash (tubes will fill with media)
- At end of backwash, remove sampler and record tallest tube that is completely full
- Calculation
- Change in depth determined by tallest tube full of media (L_{Δ})

$$\left(\frac{L_{\Delta}}{D_{original}} \right) \times 100 = \% \text{ bed expansion}$$



INTERPRETATION OF RESULTS

- Bed expansion less than desired will not be enough to wash out all the accumulated particulate contaminants
 - Perform physical inspection to find areas that are inadequately backwashed
 - Investigate underdrain for even backwash water distribution
 - Media may have to be removed
 - Inspect underdrain holes/nozzles for clogging
 - Inspect air-scour system (if applicable) to ensure sufficient air is being injected
- Bed expansion higher than desired will wash out filter media (carryover)

INTERPRETATION OF RESULTS

- If plant lime-softens, perform carbonate precipitation analysis to see if media is encrusted with carbonate
- Ensure media and backwash requirements still meet original specifications
- Backwash rate will require season adjustments based on water temperature

WATER TEMPERATURE VS. BACKWASH RATES

If backwash flow rates stay the same, year-round, you will get a higher bed expansion during colder water temps than warmer water temps

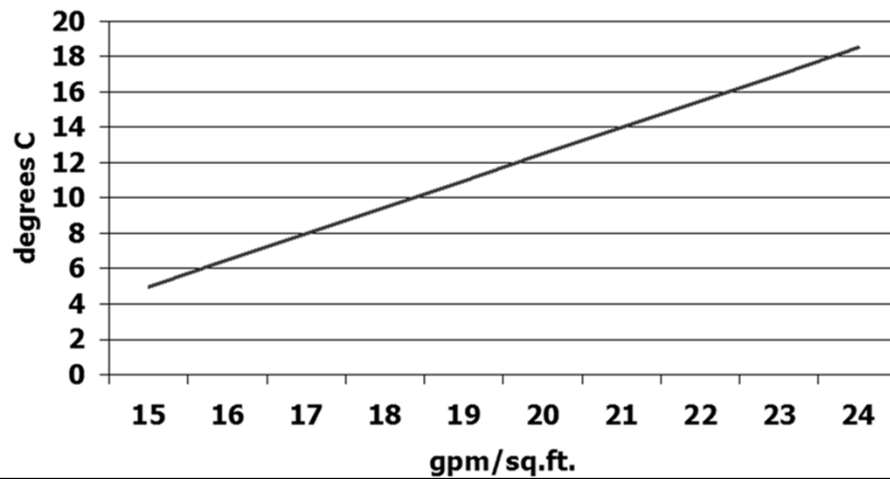
- If rates are not changed during summer and winter months
 - Mudballs may occur during the summer
 - Media loss may occur during the winter
- Colder water temps need lower backwash rates
- Warmer water temps need higher backwash rates

Check bed expansion seasonally

- Chart water temperature and backwash rate that allows a 50% bed expansion throughout the year
- If you have different filter designs, do one for each design

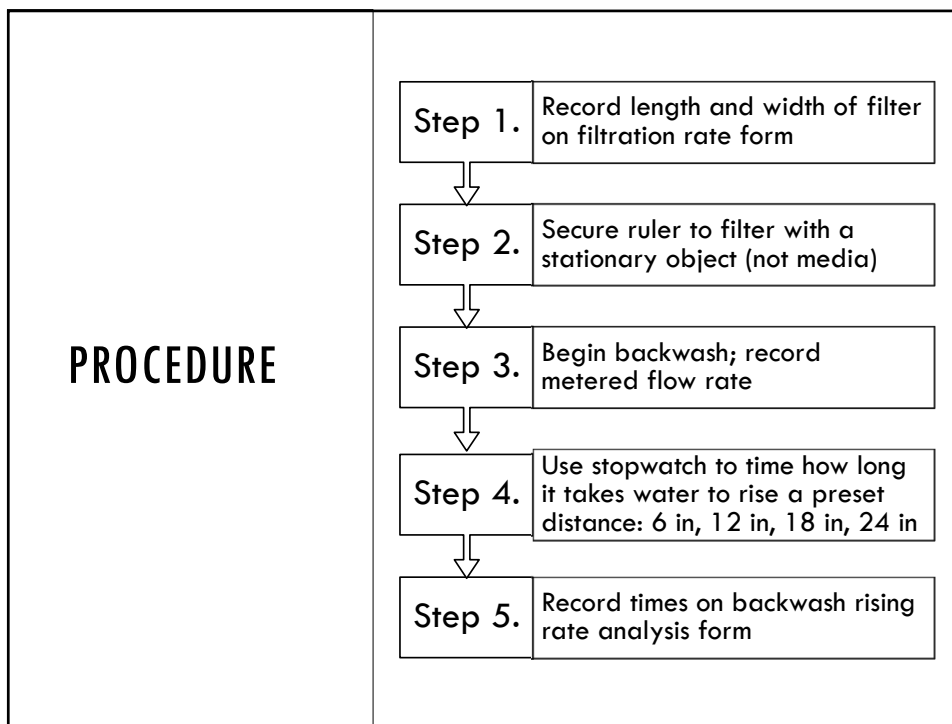
WATER TEMPERATURE VS. BACKWASH RATES

WATER TEMPERATURE VS. BACKWASH RATES



BACKWASH RISING RATE ANALYSIS

Chapter 9



BACKWASH RISING RATE ANALYSIS Calculations – Formulas from FTC WT Formula Book	Water Treatment Mathematical Formulas 6 th Edition Hook Gauge $\text{Volume, gal} = (\text{Filter Bay Length, ft})(\text{Filter Bay Width, ft})(\text{Water Drop, ft})(7.48 \text{ gal/ft}^3)$ $\text{Average Time, sec} = \frac{\text{Test}_1, \text{sec} + \text{Test}_2, \text{sec} \dots + \text{Test}_n, \text{sec}}{\text{Number of Tests (n)}}$ $\text{Average Time, min} = \frac{\text{Average Time, sec}}{60 \text{ sec/min}}$ $\text{Sand Area, ft}^2 = (\text{Sand Bed Length, ft})(\text{Sand Bed Width, ft})$ $\text{Filtration Rate, gal/min} = \frac{\text{Volume, gal}}{\text{Average Time, min}}$
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INTERPRETATION OF RESULTS

- Does the calculated backwash flow rate match the backwash flowmeter reading
 - If no, redo the test
 - If still no, get flowmeter calibrated
- Bed expansion too low – mudball formation, shortened filter runs, turbidity breakthrough
- Bed expansion too high – media loss

Backwash Flow Rate	Bed Expan., %	Action Needed
Low	<40%	↑ backwash rate and repeat bed analysis
Low	40-50%	↑ backwash rate and repeat bed analysis
Low	>50%	Check water temp*
Correct	<50%	"cementing" of filter?**
Correct	40-50%	None
Correct	>50%	Check effective size and uniformity coefficient
High	<40%	"cementing" of filter?
High	40-50%	"cementing" of filter?
High	>50%	↓ backwash flow rate and repeat bed expansion analysis



BACKWASH WATER TURBIDITY ANALYSIS

Chapter 10

BACKWASH WATER TURBIDITY ANALYSIS

IESWTR requires filters to produce a filtered water turbidity of 0.3 NTU within 30 minutes of the start of the filter run

Washing a filter until water runs clear can impede in meeting this requirement

- Increases ripening period after backwash
- Leaving a small portion of particles in the filter media will reduce or eliminate turbidity spikes when filter is put back into service
- 10-15 NTU

BACKWASH WATER TURBIDITY ANALYSIS

Equipment needed

- Backwash turbidity evaluation form
- Stopwatch
- Bucket with rope
- 30 100-mL sample bottles marked in 1-minute increments
- Benchtop turbidimeter

PROCEDURE

Label sample bottles

One operator will collect samples, one will keep the stopwatch

- Collect samples from backwash collector channel that all the backwash water troughs empty into

Following SOP, start backwash & start stopwatch

At 1-minute, lower bucket to collect sample

- Transfer sample from bucket to bottle and empty bucket into filter

Repeat every minute until normal backwash procedure is complete

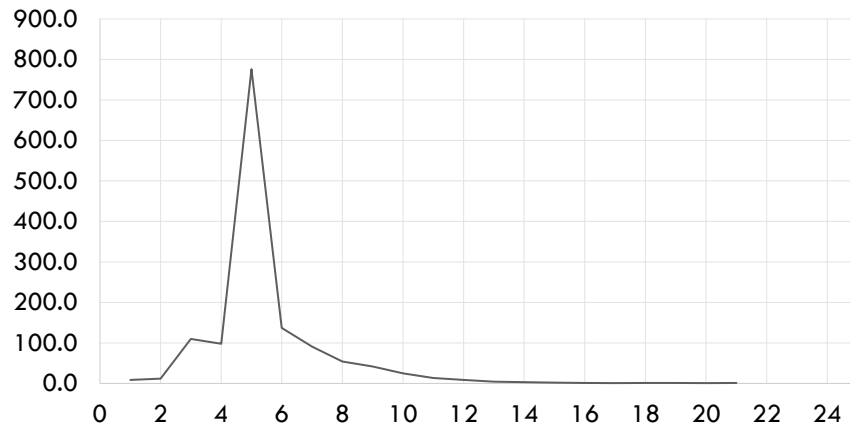
Take all samples to lab to read turbidity results

- Complete turbidity evaluation form

Graph results

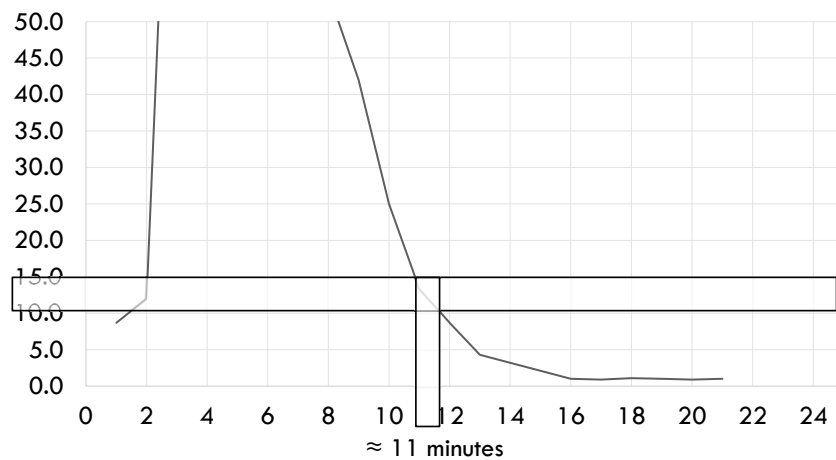
INTERPRETATION OF RESULTS

Turbidity (NTU) vs Backwash Time (minutes)



INTERPRETATION OF RESULTS

Turbidity (NTU) vs Backwash Time (minutes)





TOP OF GRAVEL FOOTPRINT ANALYSIS

Chapter 11

TOP OF GRAVEL FOOTPRINT ANALYSIS

Gravel support bed evenly distributes water throughout filter during backwash as well as supporting finer media on filter surface

Causes of gravel bed to be unlevel

- Incorrect installation
- Improper backwash procedure
 - Open valve slowly to prevent bed shifts

Indicators

- Media boil
- Dead zones
- Excessive mud in filter in one or more areas
- Media separation

DETERMINING THE POINTS OF MEASUREMENT

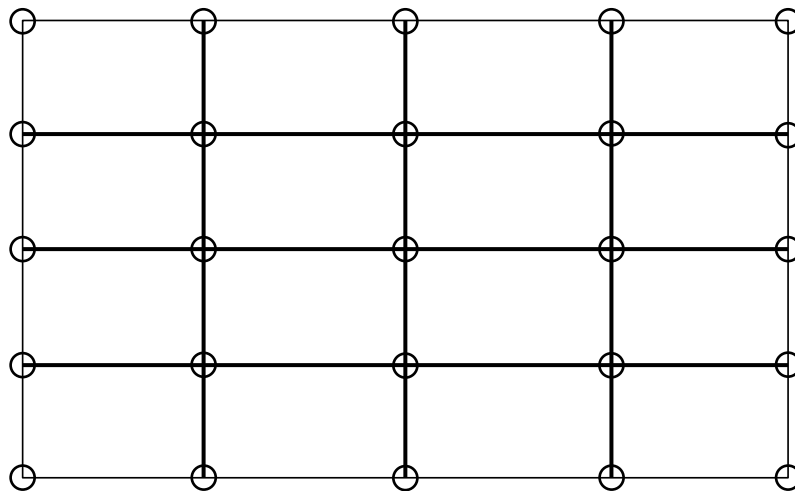
Evaluation

- Top of gravel (footprint) must be measured

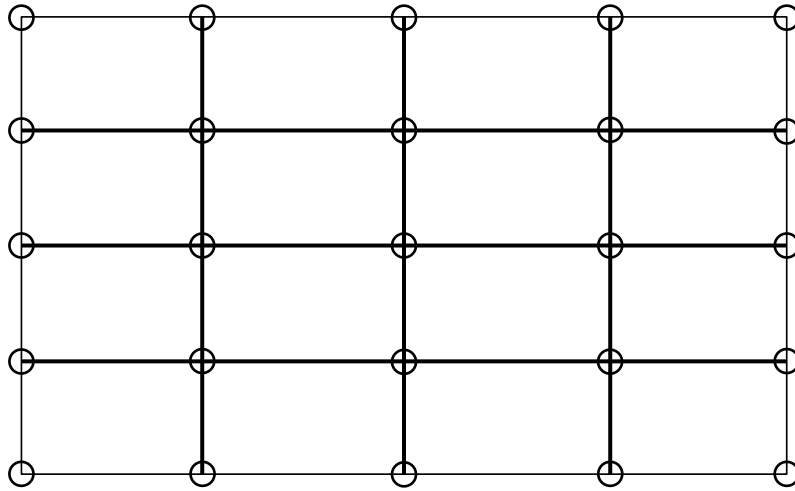
Procedure

- Along filter length, divide filter in half, then half, then half again
- Along filter width, divide filter in half, then half, then half again
- Take measurements at all points that lines cross and where lines meet the touch filter walls and corners

DETERMINING THE POINTS OF MEASUREMENT



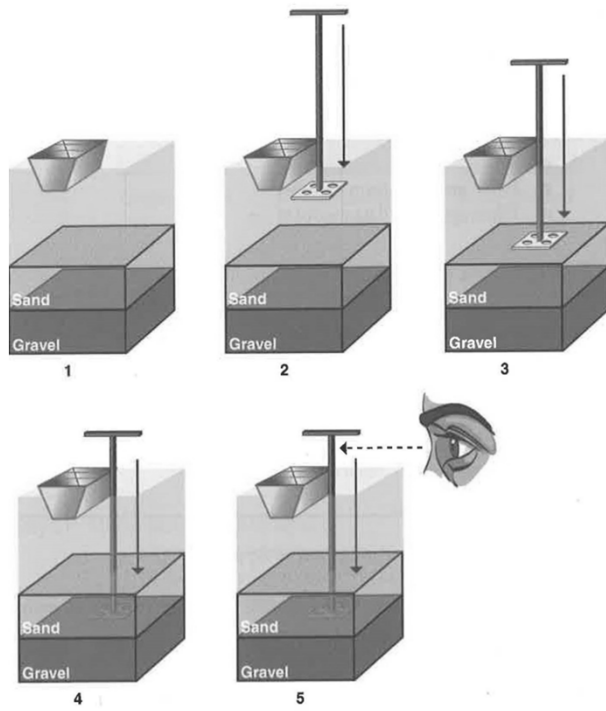
DETERMINING THE POINTS OF MEASUREMENT



PROCEDURE - METHOD 1: FLUIDIZED BED

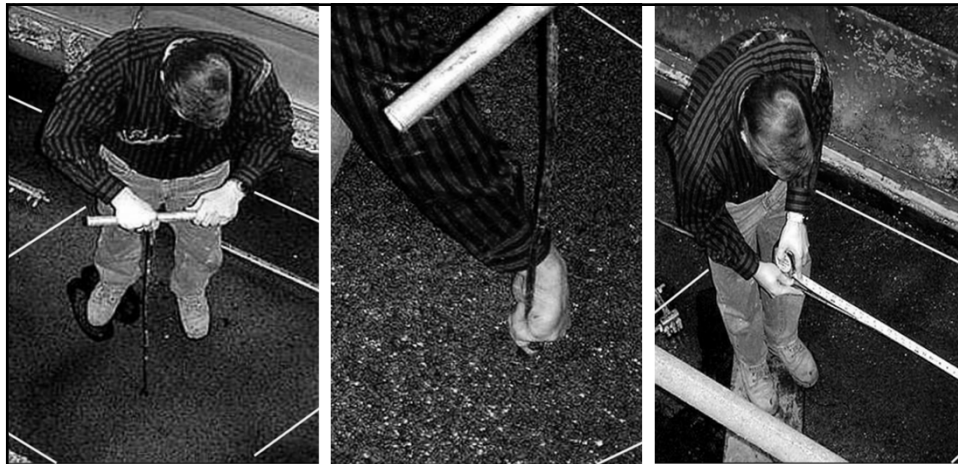
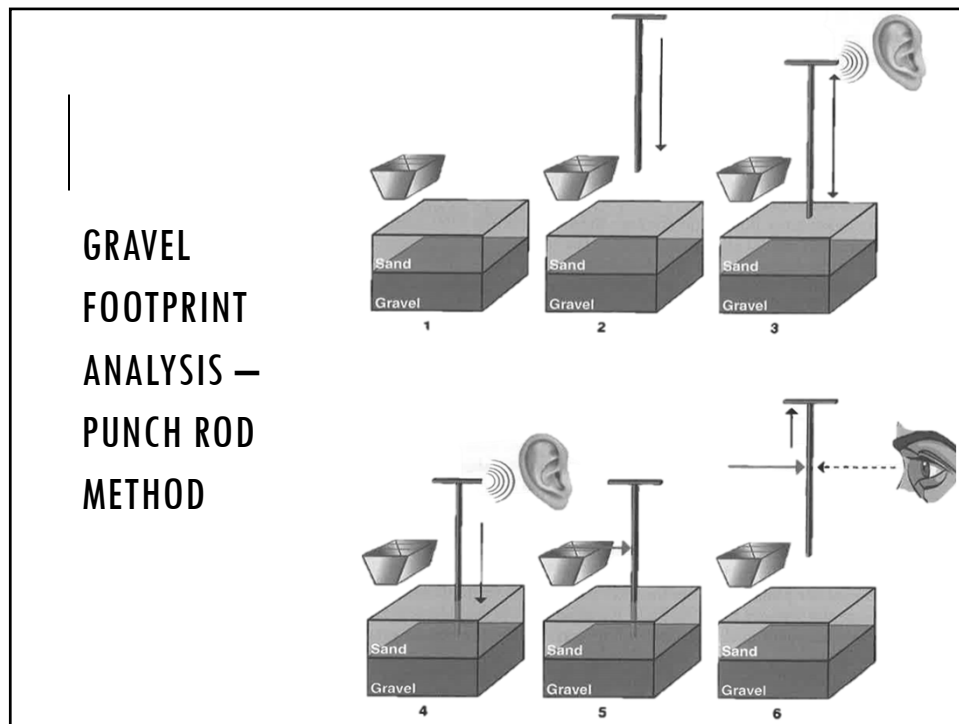
- After meeting all safety requirements, evaluation team may enter filter and stand in backwash trough
- Begin backwash
- When backwash water is at its peak flow, push punch plate into fluidized media
- Continue to press the punch plate down through the sand bed until it contacts with gravel bed
- Take measurement of depth of punch plate
- Repeat at each location determined
- Analyze values for levelness
- Most accurate method

GRAVEL FOOTPRINT ANALYSIS — FLUIDIZED BED METHOD



PROCEDURE - METHOD 2: PUNCH ROD

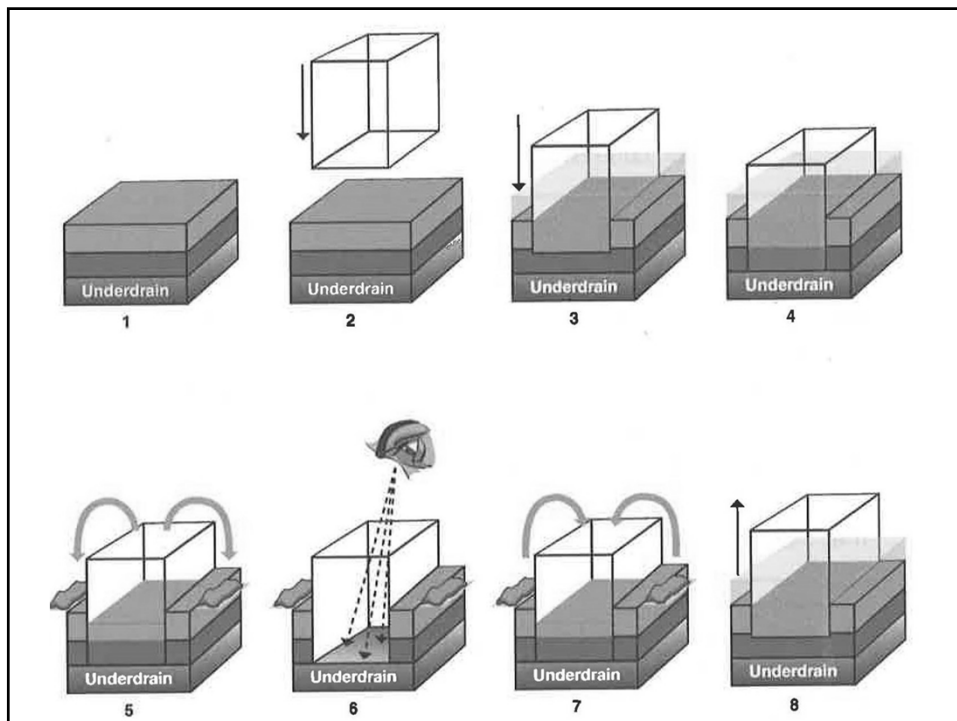
- After meeting all safety requirements, evaluation team may enter filter and stand on plywood on media
- At predetermined locations, slowly insert punch rod into media until gravel is reached
 - You can tell by the crunching sound and feel created by the rod
- Measure depth from gravel to top of media measured on rod
- Repeat at each predetermined location in filter
- Analyze values for levelness



TOP OF GRAVEL FOOTPRINT ANALYSIS

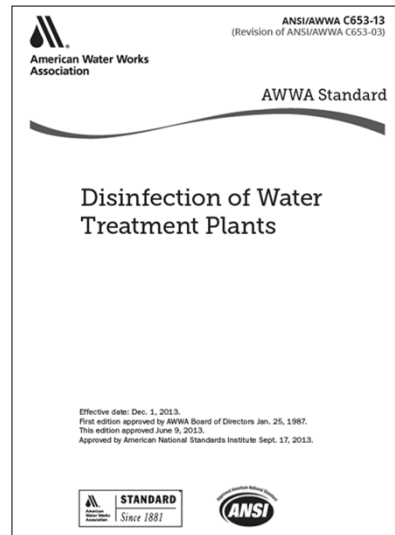
PROCEDURE - METHOD 3: EXCAVATION

- Place filter excavation box on surface of filter
- Open valve slightly to fluidize media and allow box to be pushed down to gravel support layer
- Remove all media from inside excavation box
- Once gravel bed or underdrain is exposed, place pole across top of troughs to provide level point of reference
- Measure distance from top of gravel to bottom of pole
- Repeat in all measurement locations
- Analyze results for levelness



DISINFECTION

- Filter has been contaminated by those working on and in the filter media
 - Disinfection must take place before the filter is placed back into service
 - Follow AWWA Standard C653, Disinfection of Water Treatment Plants or the plant's pre-approved media-disinfection guidelines
- Granular activated carbon (GAC) cannot be disinfected, so special care should be used to protect against contamination

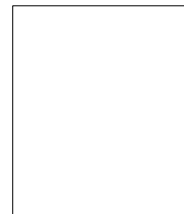
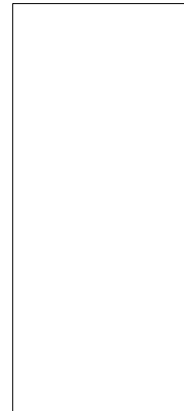


CALCULATIONS

- Can be difficult because all the measurements are the distance from the top down to the gravel support bed
 - Inputting this raw data into a spreadsheet would produce an inverted chart
 - Use filter blueprints to determine the distance from top of wash-water trough to top of gravel bed
 - Subtract field measurements from top of gravel bed for distance

Generating a Three-Dimensional Graph

- Input data from top of gravel footprint form into spreadsheet



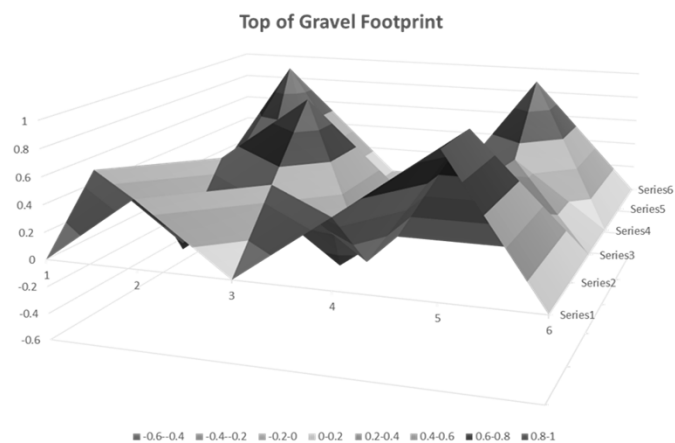
Top of Gravel Footprint Form

Date: 1-1-11 Filter ID: # 10
 Safety Officer: ST Filter Insertion: DN
 Filter Operator: CAL

Designed Distance (Top of Wastewater Trough to Top of Gravel Support Bed) 54 inches

SV 54 0	SV 53 1	SV 53 1	SV 53 1	SV 53 -1	SV 52 -3
SV 54 0	SV 54 0	SV 53 1	SV 53 1	SV 53 1	SV 53 1
SV 54 1	SV 53 1	SV 54 0	SV 54 0	SV 54 0	SV 54 0
SV 52 2	SV 53 1	SV 53 -1	SV 52 2	SV 52 3	SV 52 2
SV 54 3	SV 53 2	SV 53 -1	SV 54 0	SV 53 1	SV 54 0
SV 52 2	SV 54 0	SV 54 0	SV 54 0	SV 54 0	SV 54 0

TOP OF GRAVEL FOOTPRINT



INTERPRETATION OF RESULTS

- If graph is flat, support bed is in good shape
- If graph contains hills and valleys, gravel support bed has been disrupted leading to filter performance issues
- Any movement greater than $\pm 1/2$ inch would indicate possible gravel movement
 - Any movement greater than $3/4 - 1$ inch vertically indicates a serious problem
- Compare graph with areas that have been identified as problem areas in filter in previous steps
 - "Hills" tend to dead areas in filter
 - "Valleys" indicate boiling or media carryover may occur

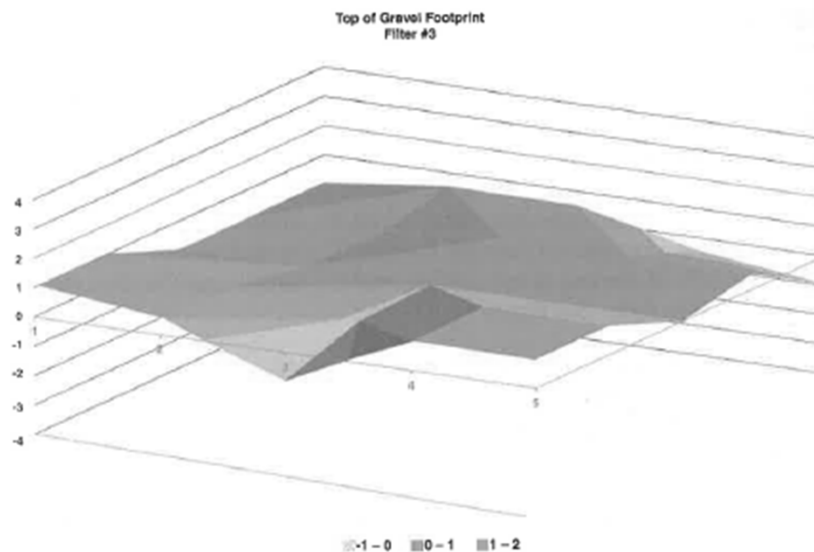
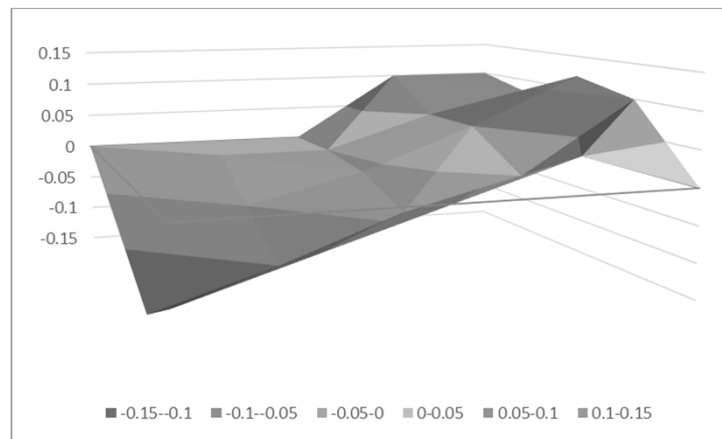
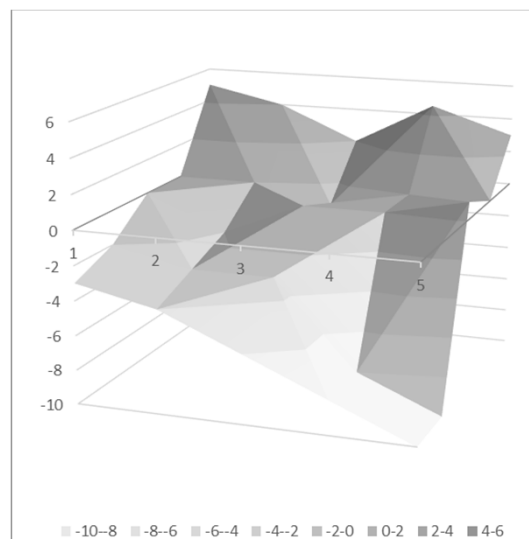


Figure 11-6 When a graph is generated, the filter will not be completely flat. Expect to find a small amount of ripple, but no more than ± 1 in. from the designed level.

TOP OF GRAVEL FOOTPRINT



TOP OF GRAVEL FOOTPRINT



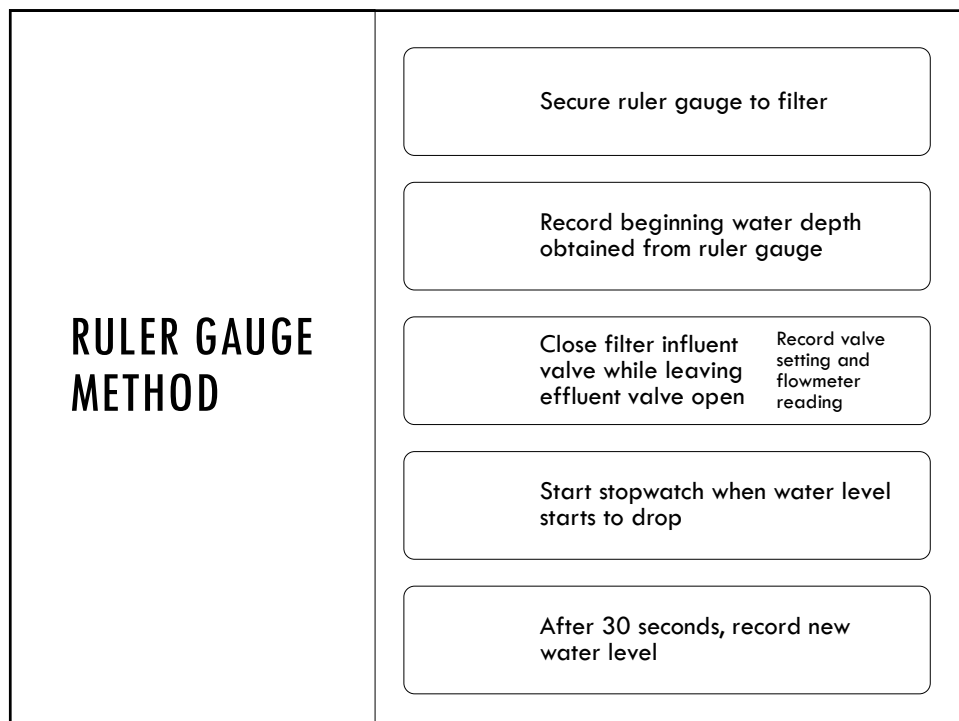
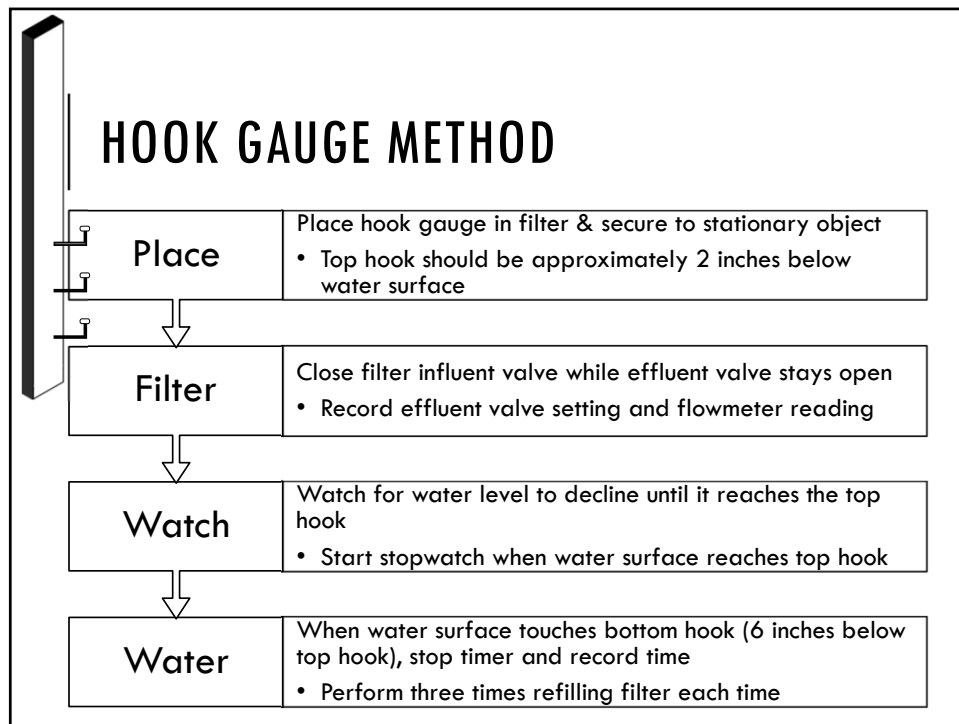


FILTRATION RATE ANALYSIS

Chapter 12

FILTRATION RATE ANALYSIS

- Quick simple method to check filtration rate and flow rate
- Can determine if filters effluent meter is calibrated properly
- TN Design Criteria 4.2.1(b)(1)
 - The nominal rate shall be 2 gpm/ft² of filter area for turbidity removal plants, and 3 gpm/ft² of filter area for iron removal plants
- 0400-45-01-.17(12)(b)
 - All public water systems which utilize a filtration system shall use the following bed specifications and not exceed the following rates of filtration
 - High-Rate Filtration - 4.0 gallons per minute per square foot for turbidity removal



FILTRATION RATE ANALYSIS

Calculations – Formulas
from FTC WT Formula
Book

Water Treatment Mathematical Formulas

6th Edition

Filtration

Hook Gauge

$$\text{Volume, gal} = (\text{Filter Bay Length, ft})(\text{Filter Bay Width, ft})(\text{Water Drop, ft})(7.48 \text{ gal/ft}^3)$$

$$\text{Average Time, sec} = \frac{\text{Test}_1, \text{sec} + \text{Test}_2, \text{sec} \dots + \text{Test}_n, \text{sec}}{\text{Number of Tests (n)}}$$

$$\text{Average Time, min} = \frac{\text{Average Time, sec}}{60 \text{ sec/min}}$$

$$\text{Sand Area, ft}^2 = (\text{Sand Bed Length, ft})(\text{Sand Bed Width, ft})$$

$$\text{Filtration Rate, gal/min} = \frac{\text{Volume, gal}}{\text{Average Time, min}}$$

$$\text{Filtration Rate, gal/min/ft}^2 = \frac{\text{Filtration Rate, gal/min}}{\text{Sand Area, ft}^2}$$



TURBIDITY ANALYSIS

Chapter 13

TURBIDITY ANALYSIS



Turbidity is made up of inorganic (silt, clay) material, organic materials, or microscopic organisms (*Crypto* or *Giardia*)

- Protozoans such as *Crypto* or *Giardia*, while in cyst form, are highly resistant to disinfection yet large enough to be filtered out of water

IESWTR reinforced importance of filter operation

- Maximum allowable turbidity of 0.3 NTU in 95% of treatment plant's combined filter effluent
- If individual filter exceeds 1.0 ntu for two consecutive 15-minute periods at any time during a period of 3 consecutive months, a filter profile must be performed

PARTICLE COUNTING

- Can show spiking in filter before it appears in turbidity
- Allows focus on specific size ranges
 - 7-12 μm for *Giardia*
 - 3-5 μm for *Cryptosporidium*
- By also measuring incoming particle counts, an estimated log (1-log, 2-log, etc) removal could be determined



ONLINE TURBIDIMETER PROCEDURE

- If online turbidimeter installed, using the following time intervals, record that turbidity on the turbidity evaluation form
- Interval 1 (hour one)
 - Record reading every minute
- Interval 2 (hours two through four)
 - Record turbidity reading every 1 to 5 minutes
- Interval 3 (remainder of filter run)
 - Record turbidity reading every 15 minutes

LABORATORY TURBIDIMETER PROCEDURE

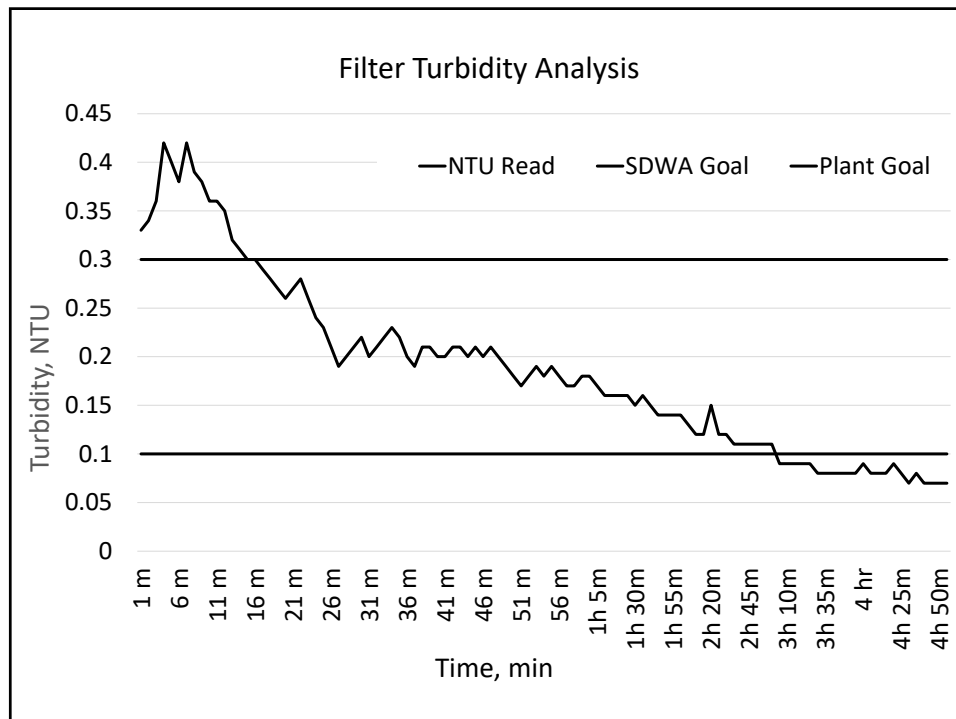
- Interval 1 (hour one)
- Collect 100-mL sample every minute
- Interval 2 (hours two through four)
- Collect 100-mL sample every 1-5 minutes
- Interval 3 (remainder of filter run)
- Collect 100-mL sample every 15 minutes

Have one team take samples to lab and read while the other team stays at the filter to continue collecting samples

GENERATING THE TURBIDITY GRAPH

Full Filter Run Turbidity Analysis

- Create spreadsheet (see example p. 132-133)
- Input collected data and create graph
- Print copy of graph to put with turbidity evaluation form



Collect samples from filter influent and effluent using the same process as turbidity analysis

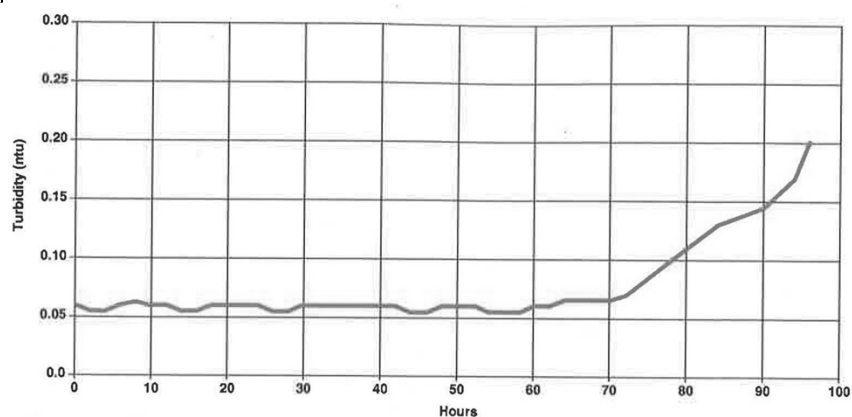
- Graph data and calculate log removal value

$$\text{LRV} = \log \left(\frac{P_I}{P_E} \right)$$

Where: P_I = # of particles in filter influent
 P_E = # of particles in filter effluent

PARTICLE COUNTS TO DETERMINE LOG REMOVAL VALUE (LRV)

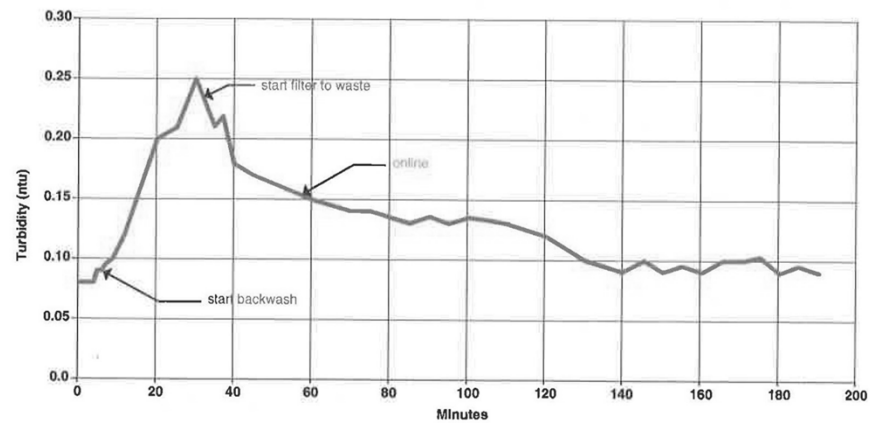
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-5 Excessive filter run time

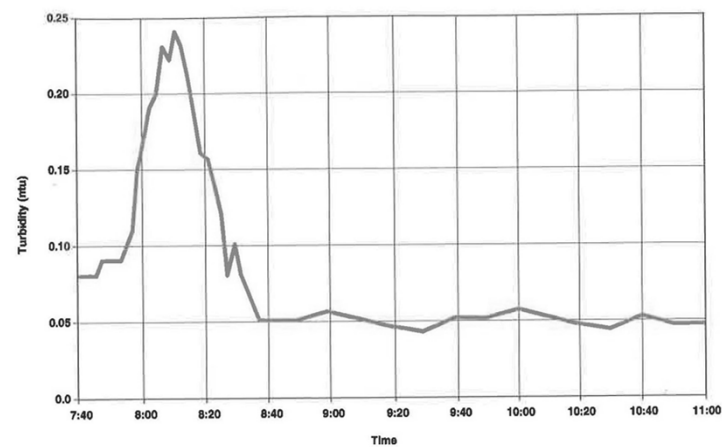
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-6 Excessive ripening time

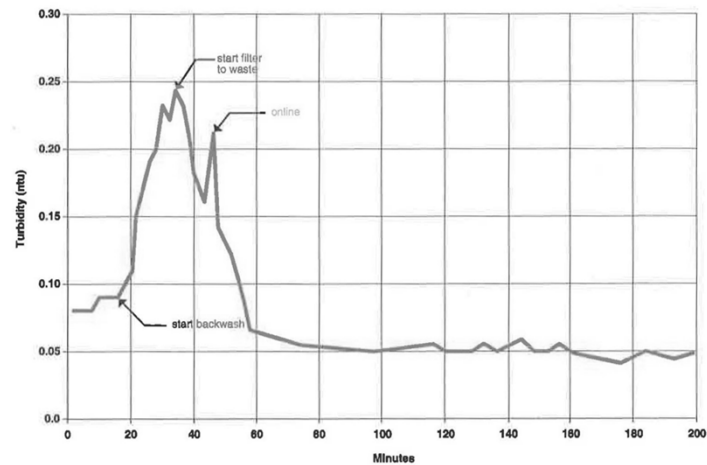
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-7 Typical filter ripening

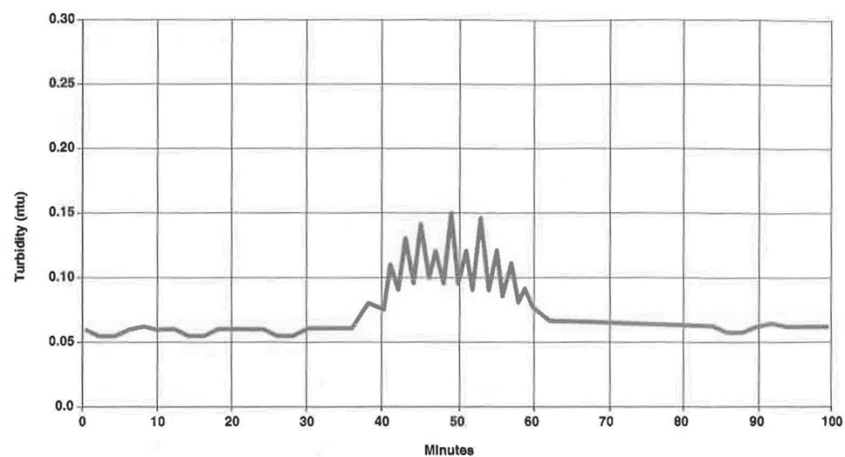
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-8 Filter-to-waste time too short

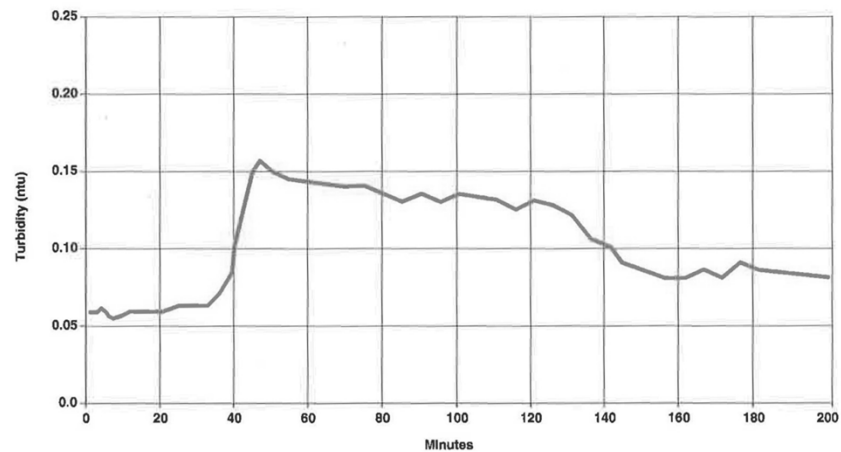
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-9 Hydraulic surging

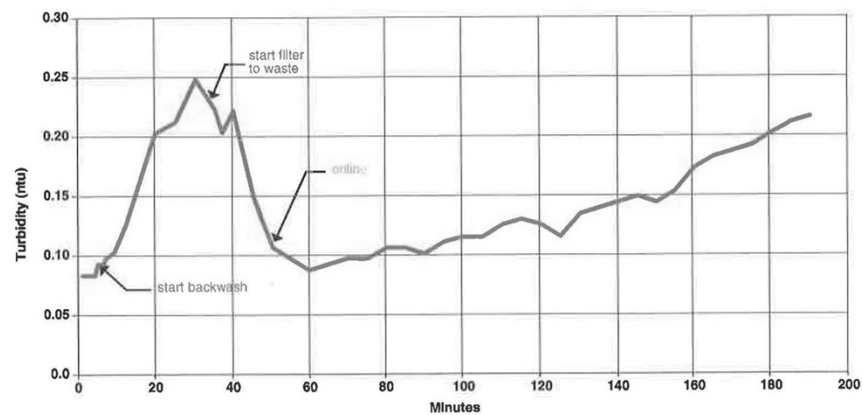
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-10 Step changes

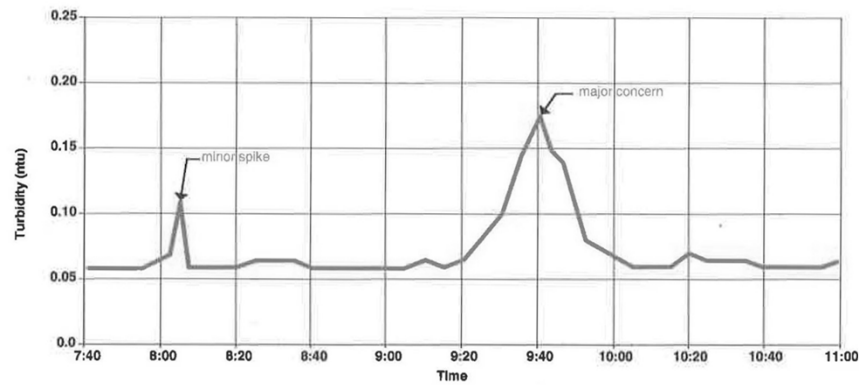
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-11 Rapidly deteriorating filter quality

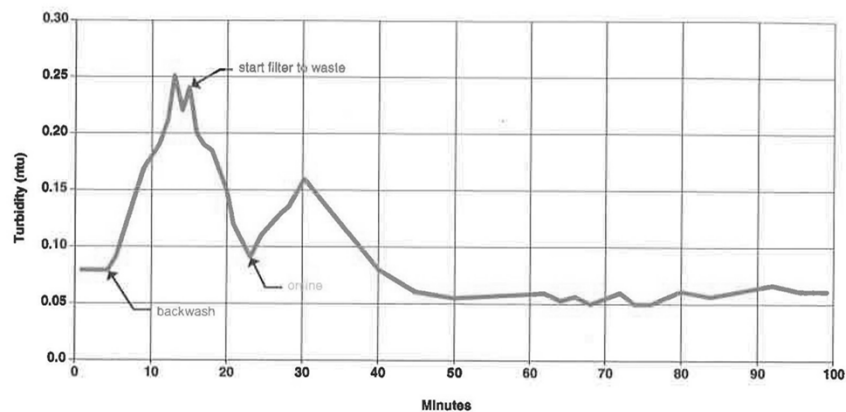
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-12 Spikes

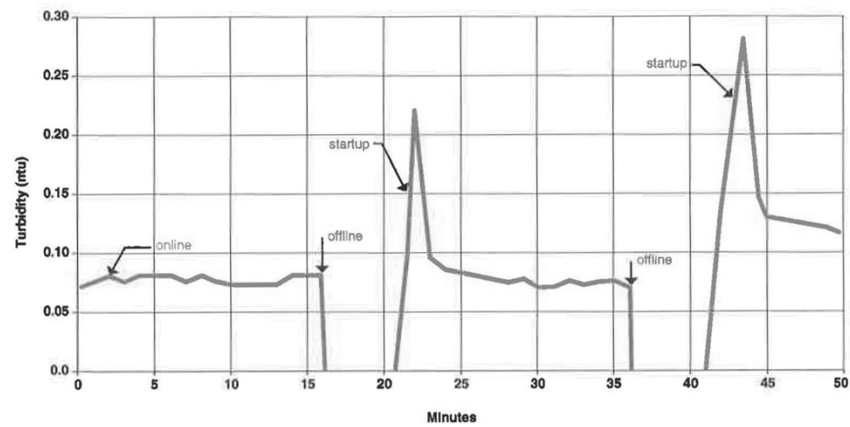
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-13 Secondary spikes

INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-14 Start/stops



Department of
Environment &
Conservation

MUDBALL ANALYSIS

Chapter 14

MUDBALL ANALYSIS

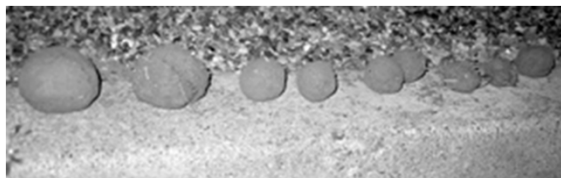
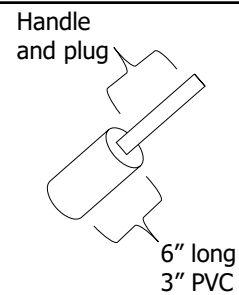
Mudballs occur when filter backwash is not operating adequately to wash out heavier mud particles near top of media

- Particles break into smaller sticky pieces which form spherical shapes and adhere to the sand around them
- Usually range from 1-2 inches or larger
- During formation, mudballs can be found on the media surface
- As they grow, the mudballs will sink deeper into the filter media typically settling along the sand-anthracite interface
- Large mudballs block filtration forcing more water through the remaining filter media
 - Leads to increased filtration rate and turbidity breakthrough

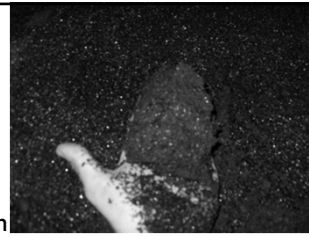
MUDBALL ANALYSIS

Equipment Needed

- Mudball analysis form
- No. 12 sieve (10 mesh)
- Small coring device
- 1-gal plastic bag
- 4-L bucket of water
- 250 mL graduated cylinder



DETERMINING POINTS OF SAMPLE COLLECTION

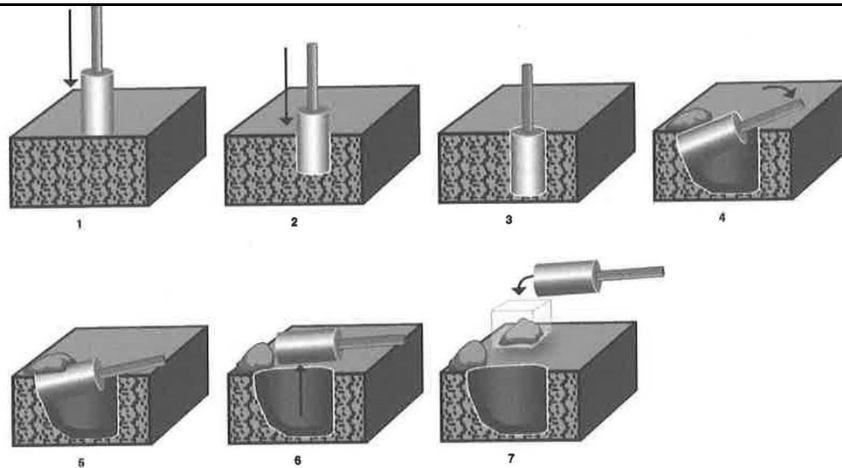


Search in areas where mudballs have been seen

Try not to collect samples in areas that the surface can reach

Sample Collection

- Backwash filter
- Drain water to below media surface
- Beginning with the first sampling point, push the mudball sampler 6 inches into the media
- Tilt the mudball sampler back until it is horizontal with the filter bed
- Lift the mudball sampler, keeping it horizontal
- Empty into a plastic baggie
- Repeat these steps for remaining sampling spots, placing all samples into same bag



SAMPLE COLLECTION

SAMPLE PREPARATION



**DO NOT
WASH
sample
once in
laboratory**



**Place No. 12
sieve in 4-L
bucket of
water so
sieve is
nearly
submerged**



**Place
handful of
media from
bag into
sieve**



**Raise and
lower sieve
in water
Any
mudballs
present will
be retained
on sieve**

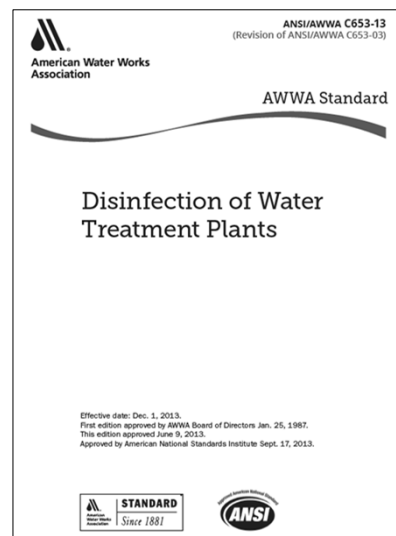


**Continue
until all
media has
been
placed and
sieve**

If mudballs fill sieve, gently
remove to paper towel and
continue separating media
onto sieve

DISINFECTION

- Filter has been contaminated by those working on and in the filter media
 - Disinfection must take place before the filter is placed back into service
 - Follow AWWA Standard C653, Disinfection of Water Treatment Plants or the plant's pre-approved media-disinfection guidelines
- Granular activated carbon (GAC) cannot be disinfected, so special care should be used to protect against contamination



SAMPLE TESTING	Fill	Fill 250 mL graduated cylinder with water to 200-mL mark • This is the initial cylinder reading
	Transfer	Transfer retained mudballs into cylinder taking care not to break them apart
	Read	Once transferred, read new volume in graduated cylinder • This is the final cylinder reading

CALCULATIONS

Sample Volume

$$\text{Media sample vol, mL} = \frac{(0.785)(D)^2(H)(N)(3785 \text{ mL/gal})}{231 \text{ in}^3/\text{gal}}$$

• Where:

D = diameter, in

H = height of sampler, in

N = number of samples taken

Therefore,

$$\text{Media sample vol, mL} = \frac{(0.785)(3 \text{ in})^2(6 \text{ in})(5)(3785 \text{ mL/gal})}{231 \text{ in}^3/\text{gal}}$$

$$\text{Media sample vol, mL} = 3482.6 \text{ mL}$$

CALCULATIONS

$$\text{Mudball Vol, mL} = \text{Vol}_{\text{Final}} - \text{Vol}_{\text{Initial}}$$

$$\% \text{ Mudballs} = \frac{\text{Mudball Vol, mL}}{\text{Media Sample Vol, mL}} \times 100$$

INTERPRETATION OF RESULTS

Percent Mudballs	Filter Condition
0.0-0.1	Excellent
0.1-0.2	Very Good
0.2-0.5	Good
0.5-1.0	Fair
1.0-2.5	Fairly Bad
2.5-5.0	Bad
>5.0	Very Bad

MUDBALL REMOVAL

- Manually using strainer basket during backwash with very low flow rate
- Passing media through sieve to retain anything greater than 1 inch
- Backwashing and chemical addition can break up mudballs
- Pump media through ejector
- Dig up hard areas of filter media
- Remove media and clean it
- Replace media

Removal of mudballs does not remove the cause of mudballs!!

- Entire backwash system and procedures should be evaluated



CARBONATE PRECIPITATION ANALYSIS

Chapter 15

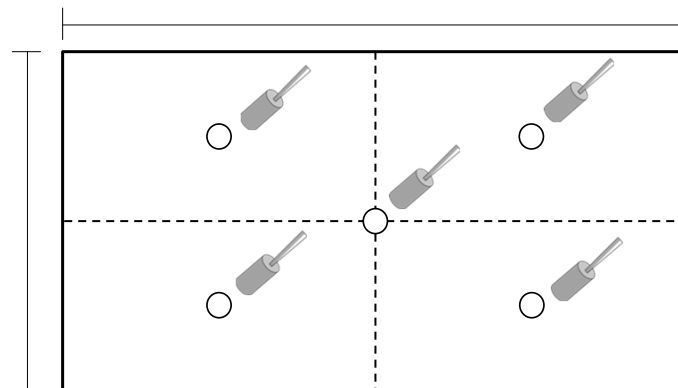
CARBONATE PRECIPITATION ANALYSIS



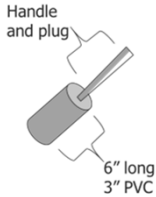
If using lime softening process, calcium carbonate can be deposited on filter media if recarbonation is not operating correctly or phosphate addition is too low

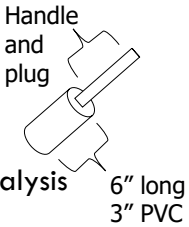
- Deposition is not likely to be removed by backwashing and will build up over time
- Changes effective size and uniformity coefficient of media due to the grain expanding from deposition
- Angular media can become rounded
- In dual media filters, the two media have less difference in densities due to encrustation
- Impact distribution through filter column
- Filter media becomes cemented together forming conglomerate "rocks"

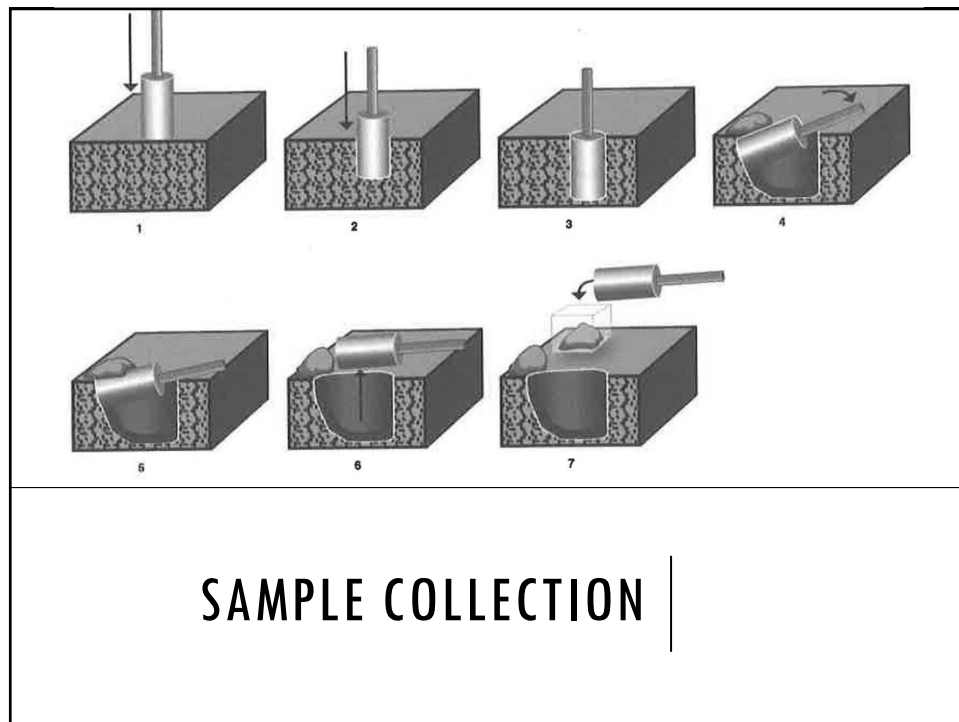
SAMPLING POINTS

Sampling point should be representative of the filter



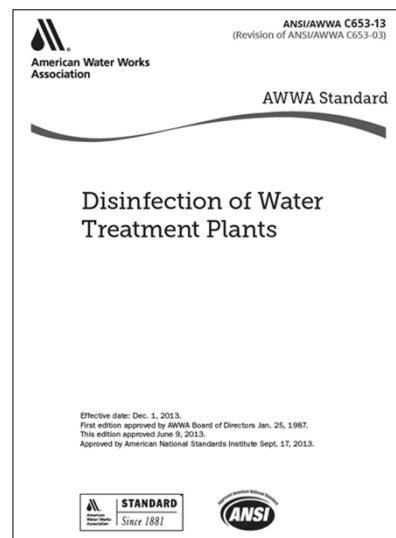
<h2>EQUIPMENT NEEDED</h2> <ul style="list-style-type: none"> ▪ Carbonate precipitation analysis form ▪ Balance ▪ Large crucibles ▪ 100-mL graduate cylinder ▪ Water squeeze bottle ▪ Two 2-L beakers ▪ Small coring device ▪ 1-gal plastic bag ▪ 4-L bucket ▪ Weighing boats 		
		 <p>Handle and plug</p> <p>6" long 3" PVC</p>

<h2>SAMPLE COLLECTION</h2> <ul style="list-style-type: none"> ▪ Can use media left in 4-L bucket from mudball analysis OR ▪ Backwash filter ▪ Drain water to below media surface ▪ Beginning with the first sampling point, push the mudball sampler 6 inches into the media ▪ Tilt the mudball sampler back until it is horizontal with the filter bed ▪ Lift the mudball sampler, keeping it horizontal ▪ Empty into a baggie ▪ Repeat this steps for remaining sampling spots, placing all samples into same bag 	 <p>Handle and plug</p> <p>6" long 3" PVC</p>
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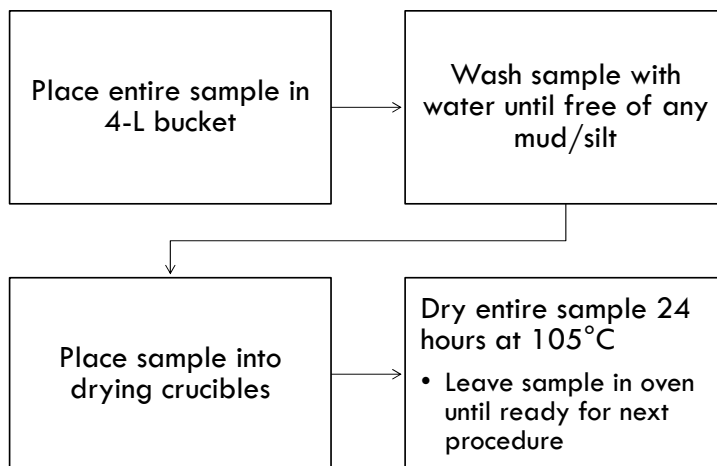


DISINFECTION

- Filter has been contaminated by those working on and in the filter media
 - Disinfection must take place before the filter is placed back into service
 - Follow AWWA Standard C653, Disinfection of Water Treatment Plants or the plant's pre-approved media-disinfection guidelines
- Granular activated carbon (GAC) cannot be disinfected, so special care should be used to protect against contamination



SAMPLE PREPARATION



TESTING OPTIONS

Testing by Weight

- Remove sample from drying oven and allow to cool in desiccator (no more than 30 minutes)
- Weight out 200 g of dried media using balance and weighing boat
 - Record as initial sample weight
- Set sample aside to be acid washed

Testing by Volume

- Fill 100-mL graduated cylinder with remaining dried media
 - Record as initial sample volume
- Set sample aside to be acid washed

ACID WASH EQUIPMENT NEEDED	<ul style="list-style-type: none">▪ Goggles▪ Gloves▪ Apron▪ Fume hood▪ 2-L of 50% HCl▪ Distilled water in squirt bottle
---------------------------------------	--

ACID WASH PROCEDURE	Weight Sample	<ul style="list-style-type: none">• Pour 50 mL of the 50% HCl into the 2-L beakers• Slowly sift weighed sample into beaker<ul style="list-style-type: none">• Squirt distilled water onto rising bubbles to prevent overflowing• Once reaction slows, more media may be added• If media is added and no reaction occurs, add more HCl, slowly• Carefully rinse acid washed media with clean water to remove acid and carbonate solution• Place acid cleaned weight sample in labeled crucible and dry for 24 hrs at 105°C
	Volume Sample	<ul style="list-style-type: none">• Repeat same process as for Weight sample

FINAL TESTING

Weight Sample

- Remove dried, acid-washed weight sample from drying oven and allow to cool in desiccator
- Weight entire sample
- Record as final sample weight

Volume Sample

- Remove dried, acid-washed volume sample from drying oven and allow to cool in desiccator
- Place sample in 100-mL graduated cylinder
- Record value as final sample volume

CALCULATIONS

- Weight of Carbonate

$$W_{\text{initial}} - W_{\text{final}} = W_{\text{carbonate}}$$

- Percentage of Carbonate

$$\text{Percent carbonate (by weight)} = \left(\frac{W_{\text{carbonate}}}{W_{\text{initial}}} \right) \times 100$$

- Volume of Carbonate

$$V_{\text{initial}} - V_{\text{final}} = V_{\text{carbonate}}$$

- Percentage of Carbonate

$$\text{Percent carbonate} = (\text{by volume}) \left(\frac{V_{\text{carbonate}}}{V_{\text{initial}}} \right) \times 100$$

INTERPRETATION OF RESULTS

- Analysis gives indication of efficiency recarbonation process
- Large values of carbonate indicate recarbonation process needs to be reviewed
- There is no industry standard
- By continuing to collect and review data, each utility can develop its own set of parameters as to what is an acceptable amount and what is unacceptable



SIEVE TESTING PROCEDURE

FOR EFFECTIVE SIZE AND UNIFORMITY COEFFICIENT
DETERMINATION

Chapter 16

SIEVE TESTING

Filter media commonly described by two components:

- Effective size (ES)
 - Sand - 0.35 mm to 0.55 mm
 - Anthracite - 0.8 mm to 1.2 mm
- Uniformity coefficient (UC)
 - Sand - not greater than 1.7
 - Anthracite - not greater than 1.85

Sieve analysis can be used to determine ES and UC, well as backwash rates

Analysis of ES and UC shows

- Media loss
- Calcium carbonate encrustation of filter media
- Head loss through media
- Backwash expansion
- L/d ratio

SIEVE TESTING PROCEDURES

- ASTM Standard C136
- ANSI/AWWA Standard B100
- This text provides methodology to be used more quickly than the standard
 - Modified procedure designed to give plant staff quick method to determine if something may be wrong in filter
 - If results are significantly differently than expected, should hire third party firm to confirm testing before investing large sums to fix issues

EQUIPMENT NEEDED

- Two team members
 - Safety officer
 - Filter insertion team member
- Safety Equipment
 - Plywood board
 - Ladder
 - Hard hat
- Equipment
 - Sieve testing data form
 - Sieves
 - No. 5
 - No. 6
 - No. 7
 - No. 8
 - No. 10
 - No. 12
 - No. 14
 - No. 16
 - No.18
 - No. 20
 - No. 25
 - No. 30
 - No. 35
 - No. 40
 - No.45
 - Collection tray

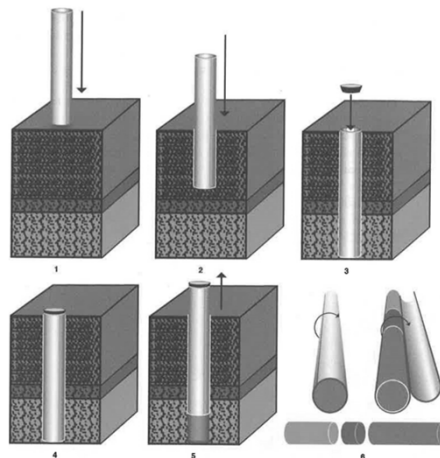
EQUIPMENT NEEDED CONT'D

- Equipment
 - Sieve shaker
 - Balance
 - Drying oven
 - Desiccator
 - Large coring device with plug or cap
 - Multiple 1-gallon plastic bags
 - Marker
 - Drying crucibles
 - Two containers
 - Wire brush

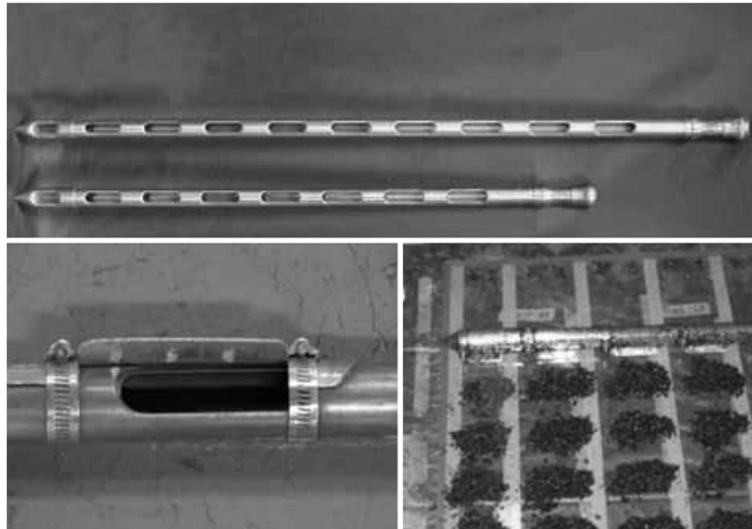


SAMPLE COLLECTION	Step 1.	Determine areas to be sampled
	↓	
	Step 2.	Backwash the filter to be sampled
	↓	
	Step 3.	Drain water completely from filter
	↓	
	Step 4.	Use large coring device, push into media until underdrain or gravel support is reached
	↓	
	Step 5.	Cap coring device and lift out of filter bed
	↓	
	Step 6.	Uncouple coring device so that the entire contents can be separated by depth
	↓	
	Step 7.	Deposit distinct layers of different media in 1-gallon plastic bag & write layer depth on bag
	↓	
	Step 8.	Repeat steps 3-7

SAMPLE COLLECTION

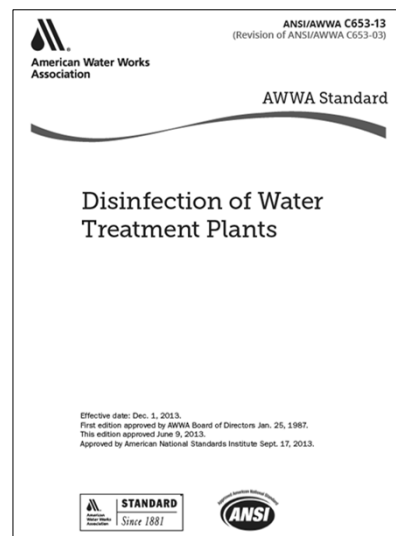


CORING DEVICE

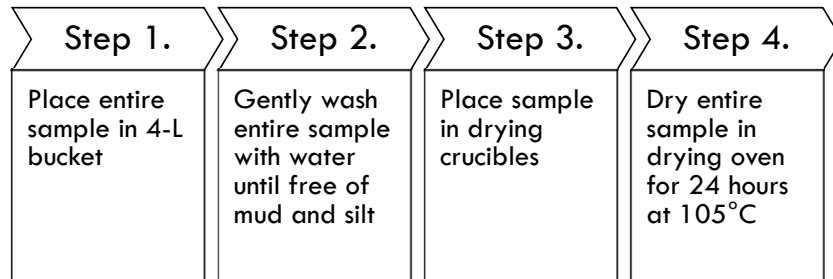


DISINFECTION

- Filter has been contaminated by those working on and in the filter media
 - Disinfection must take place before the filter is placed back into service
 - Follow AWWA Standard C653, Disinfection of Water Treatment Plants or the plant's pre-approved media-disinfection guidelines
- Granular activated carbon (GAC) cannot be disinfected, so special care should be used to protect against contamination



SAMPLE PREPARATION



SIEVE TESTING

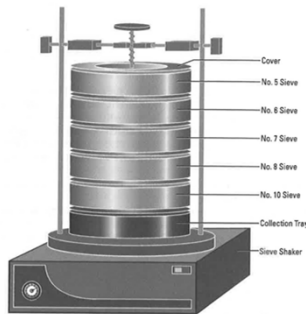
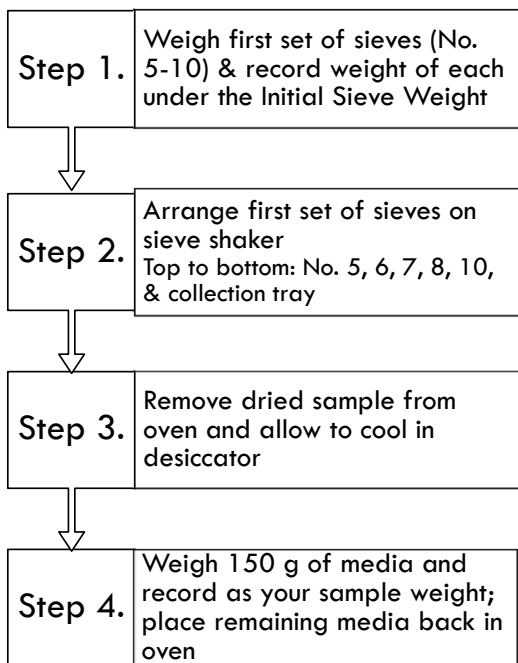


Figure 10-4 Arrangement of first set of sieves



SIEVE TESTING

Step 5. Place 150 g of media in top of sieves, secure top and begin shaking sample at a setting of 50% on shaker

- Sand - shake 10 minutes
- Anthracite - shake 5 minutes
- If media remains on No. 5 sieve, this should be sieved through a large sieve until all media passes one sieve

Step 6. After appropriate time, place media deposited in collection tray in clean container; keep for later (container #1)

Step 7. Carefully weigh each sieve with media on it with balance and record under *Final Sieve Weight* on sieve testing data form

SIEVE TESTING

Step 8.

After weighing media, place in container #2 & set aside
Turn sieve upside down light scrape underside with wire brush

Step 9.

Weigh second set of sieves (No. 12-20) & record of each under the Initial Sieve Weight

Step 10.

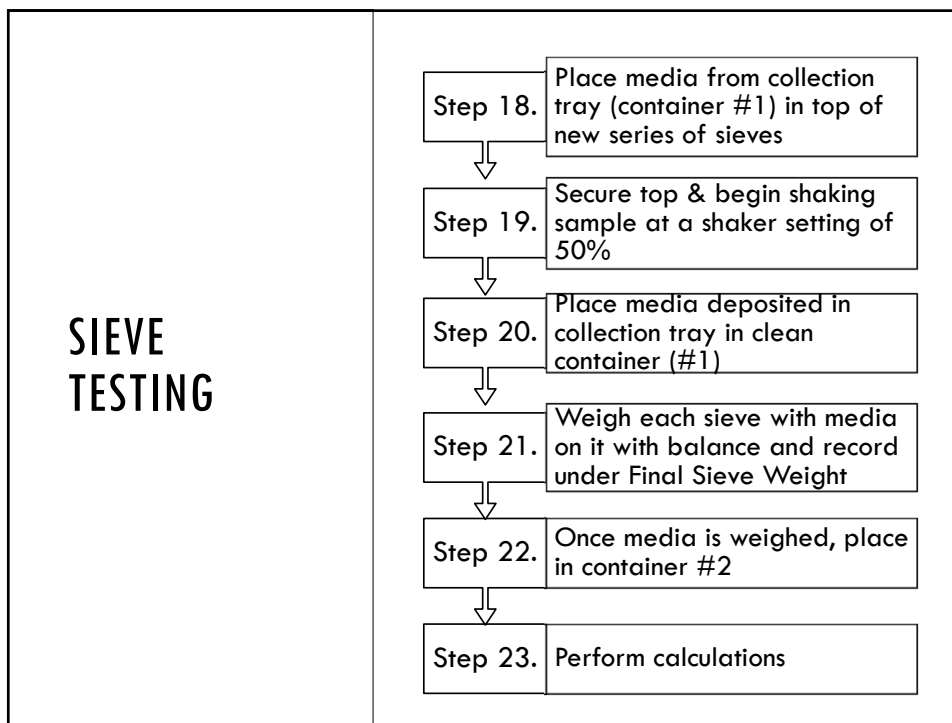
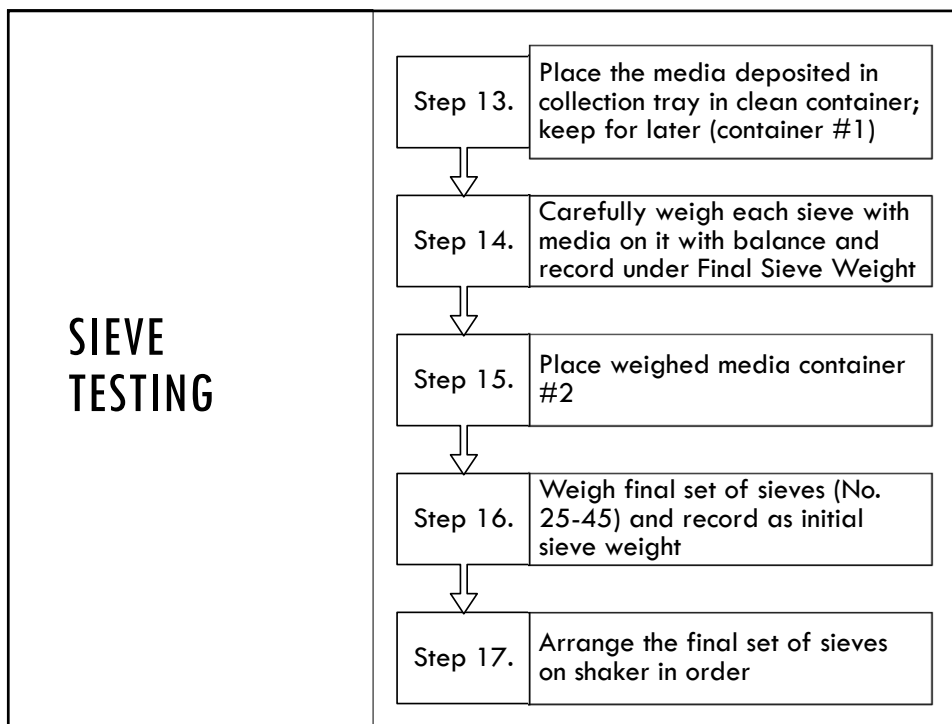
Arrange second set of sieves on shaker

Step 11.

Place media from container #1 in first sieve in top of the new series
Top to bottom: No. 12, 14, 16, 18, 20, & collection tray

Step 12.

Secure top and begin shaking sample at a setting of 50% on shaker



CALCULATIONS

Determine the individual weights of the different media sizes

Step 1. Beginning with largest sieve size, subtract initial weight from final weight; record on sieve testing data form as *Retained Weight*

$$W_f - W_i = W_r$$

W_f = final weight of sieve in grams

W_i = initial weight of sieve in grams

W_r = weight of media retained on sieve in grams

CALCULATIONS

Step 2. Create spreadsheet in Excel

$$\begin{aligned} & \text{cumulative \% passing} \\ &= \left[1 - \left(\frac{\text{cumulative weight}}{\text{total weight}} \right) \right] \times 100 \end{aligned}$$

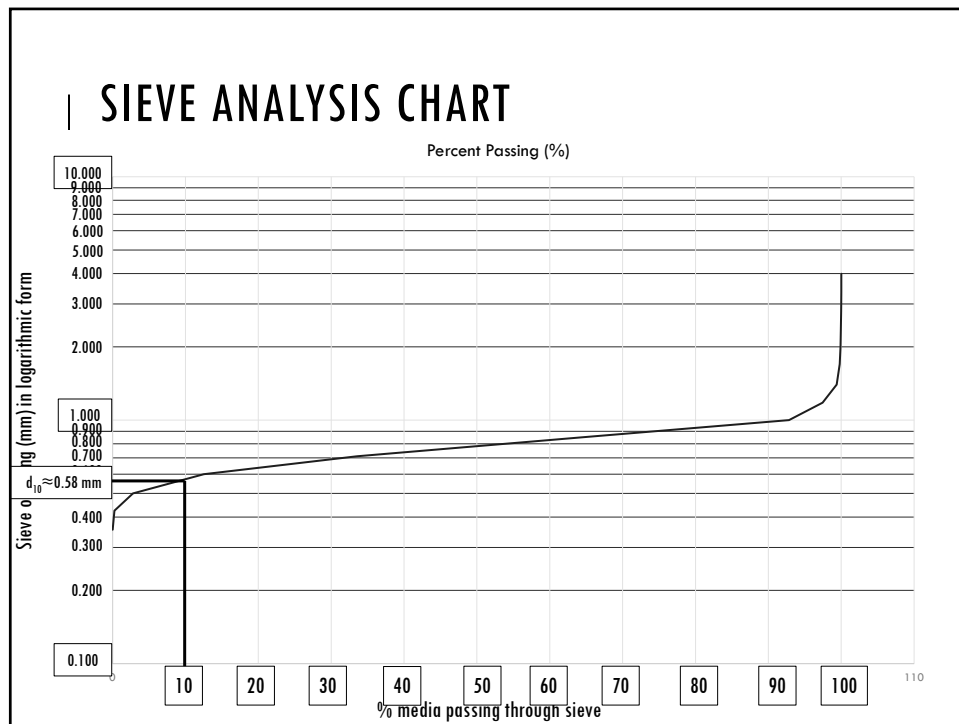
Sand Sieve (mm)	Sand Sieve (No.)	Sample Wt. (grams)	Cumulative Wt. (grams)	Percent Passing (%)
4.000	5	0.0000	0.0000	100.00
3.350	6	0.0000	0.0000	100.00
2.800	7	0.0463	0.0463	99.99
2.360	8	0.1255	0.1718	99.96
2.000	10	0.1475	0.3193	99.90
1.700	12	0.4763	0.7956	99.80
1.400	14	1.5942	2.3898	99.39
1.180	16	7.6005	9.9903	97.44
1.000	18	17.9225	27.9128	92.84
0.850	20	111.3976	139.3104	64.28
0.710	25	119.8216	259.1320	33.55
0.600	30	82.3075	341.4395	12.52
0.500	35	37.8440	379.2835	2.81
0.425	40	9.9820	389.2655	0.25
0.355	45	0.9853	390.2508	0.00
	Total Weight	390.2508		

CALCULATIONS

Step 3. Compare *Total Weight* calculated at end of *Sample Weight* column to last figure for *Cumulative Weight*

Step 4. Compare *Cumulative Weight* to the *Original Sample Weight*; value should be within 1% of original weight

- If not, media was lost somewhere in the testing procedure and results may not be accurate

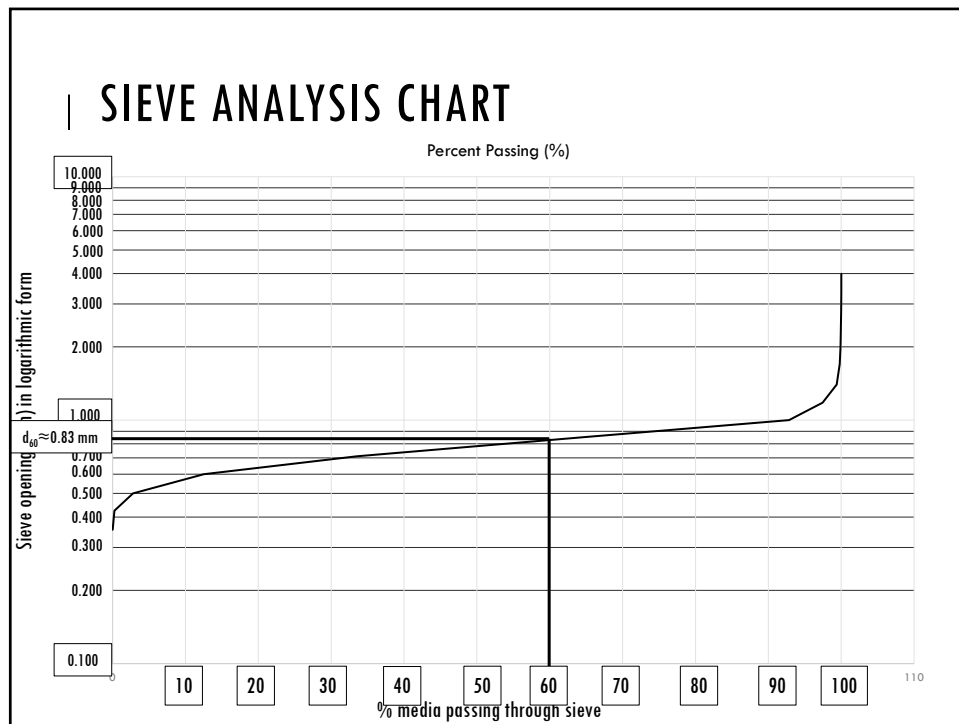


DETERMINING d_{10}

- How to find d_{10}
 - Find 10% on x-axis (horizontal)
 - Travel up until reaching graph curve
 - Travel left until reaching y-axis (vertical)
 - This value is d_{10} – record on sieve testing data sheet

In this example, 10% of the media sample is smaller than 0.58 mm (as found on previous chart)

- Is this a good value if the media sample is sand?
 - Acceptable ES according to TN Design Criteria
 - Sand - 0.35 mm to 0.55 mm
 - Anthracite - 0.8 mm to 1.2 mm



DETERMINING d_{60}

- How to find d_{60}
 - Find 60% on x-axis (horizontal)
 - Travel up until reaching graph curve
 - Travel left until reaching y-axis (vertical)
 - This value is d_{60} – record on sieve testing data sheet

In this example, 60% of the media sample is smaller than 0.83 mm (as found on previous chart)

- Is this a good value if the media sample is sand?
 - Uniformity coefficient (UC)
 - Sand - not greater than 1.7
 - Anthracite - not greater than 1.85

CALCULATING UNIFORMITY COEFFICIENT

$$\text{Uniformity Coefficient} = \frac{d_{60}}{d_{10}}$$

$$d_{10} = 0.58 \text{ mm}$$

$$d_{60} = 0.83 \text{ mm}$$

$$\text{UC} = \frac{0.83 \text{ mm}}{0.58 \text{ mm}}$$

$$\text{UC} = 1.43$$

ALTERNATIVE METHOD FOR FINDING D10 & D60

CALCIUM CARBONATE ENCrustATION

If system believes or has determined CaCO_3 scale is altering size of media, then scale needs to be removed before procedure for ES and UC is conducted

Follow procedure for Calcium Carbonate Precipitation Analysis discussed earlier



SLUDGE RETENTION PROFILE

Chapter 17

SLUDGE RETENTION PROFILE

- If too many particles (sludge) left in filter media, mudballs can form
- Profile allows staff to assess condition of filter layers and backwash effectiveness
- Also known as
 - Mud deposition profile
 - Floc retention profile
 - Turbidity profile
- Some sludge will always be left in filter
 - All levels of filter should have a retained turbidity of 30-60ntu

EQUIPMENT NEEDED

Safety

- Plywood board
- Ladder
- Hard hat

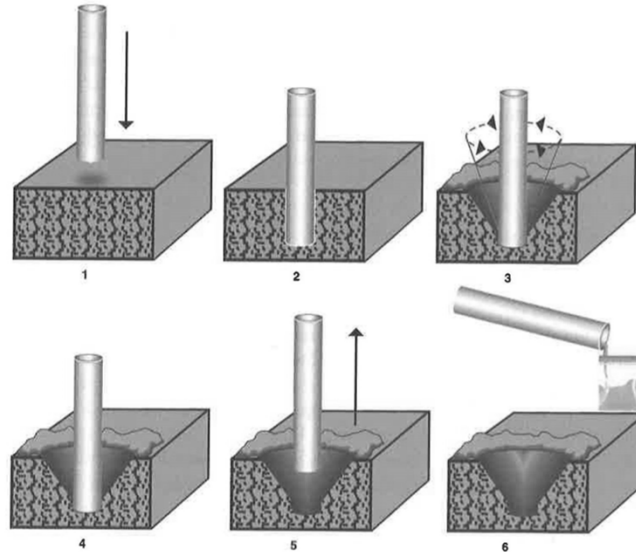
Equipment

- Sludge retention profile form
- Sludge retention core sampler
- 100-mL graduated cylinder
- 500-mL flask
- 500-mL beaker
- Benchtop turbidimeter

Equipment

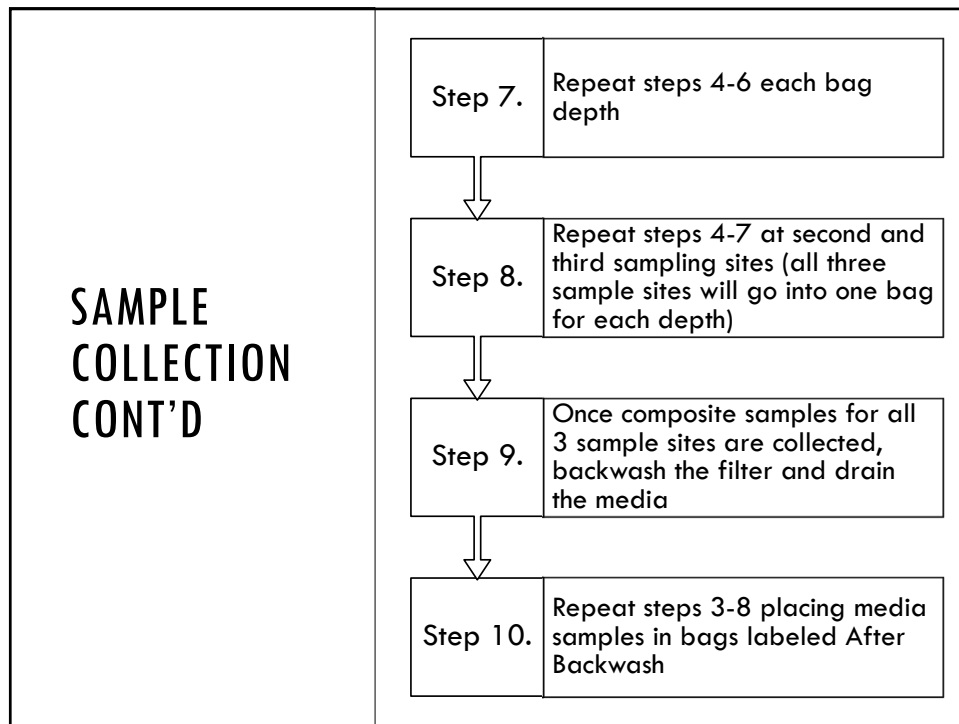
- 24-36 1-gal resealable bags
 - 1 set for before backwash and 1 set for after backwash
 - 0-2 inch
 - 2-6
 - 6-12
 - 12-18
 - 18-24
 - 24-30
 - 30-36

SAMPLE COLLECTION



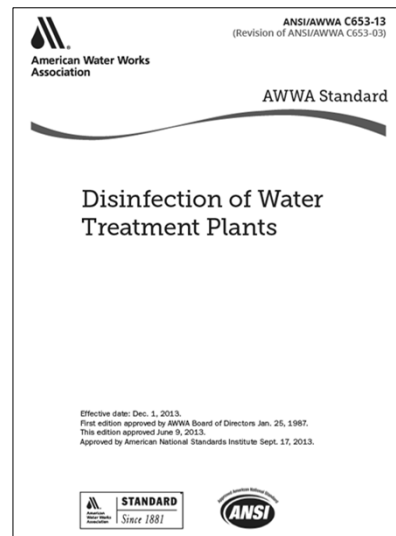
SAMPLE COLLECTION

- | | |
|---------|--|
| Step 1. | Select 3 sampling points in filter |
| Step 2. | At end of filter run, drain all water from media |
| Step 3. | Enter filter; standing on plywood, collect first sample |
| Step 4. | Gently push core sampler into media to 2-inch mark |
| Step 5. | Plug end of coring device; slowly retract sampler from media |
| Step 6. | Deposit sample in plastic bag marked 0-2 in: Before Backwash |

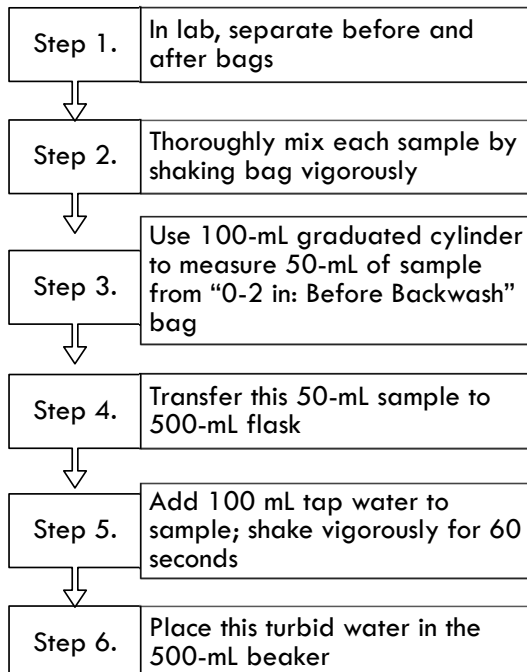


DISINFECTION

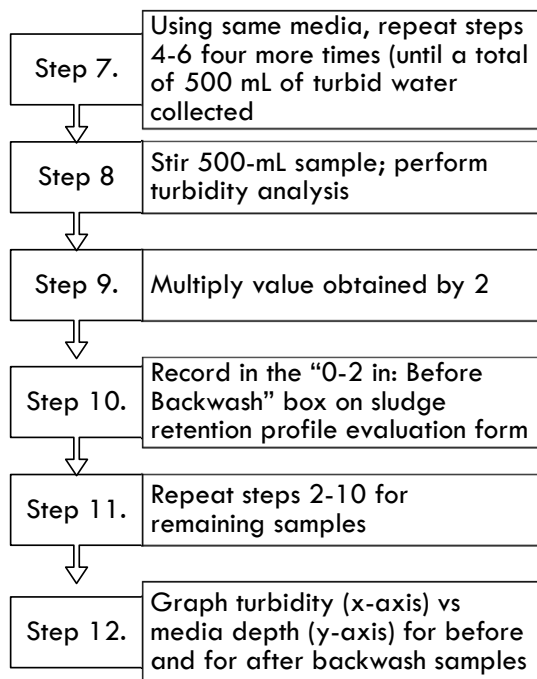
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 - Disinfection must take place before the filter is placed back into service
 - Follow AWWA Standard C653, Disinfection of Water Treatment Plants or the plant's pre-approved media-disinfection guidelines
- Granular activated carbon (GAC) cannot be disinfected, so special care should be used to protect against contamination



SAMPLE PREPARATION



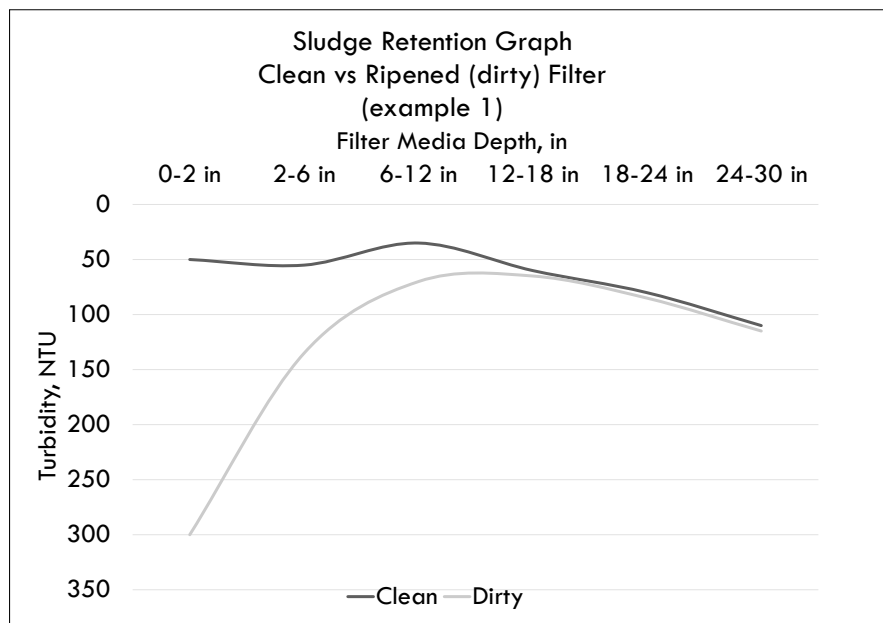
SAMPLE PREPARATION

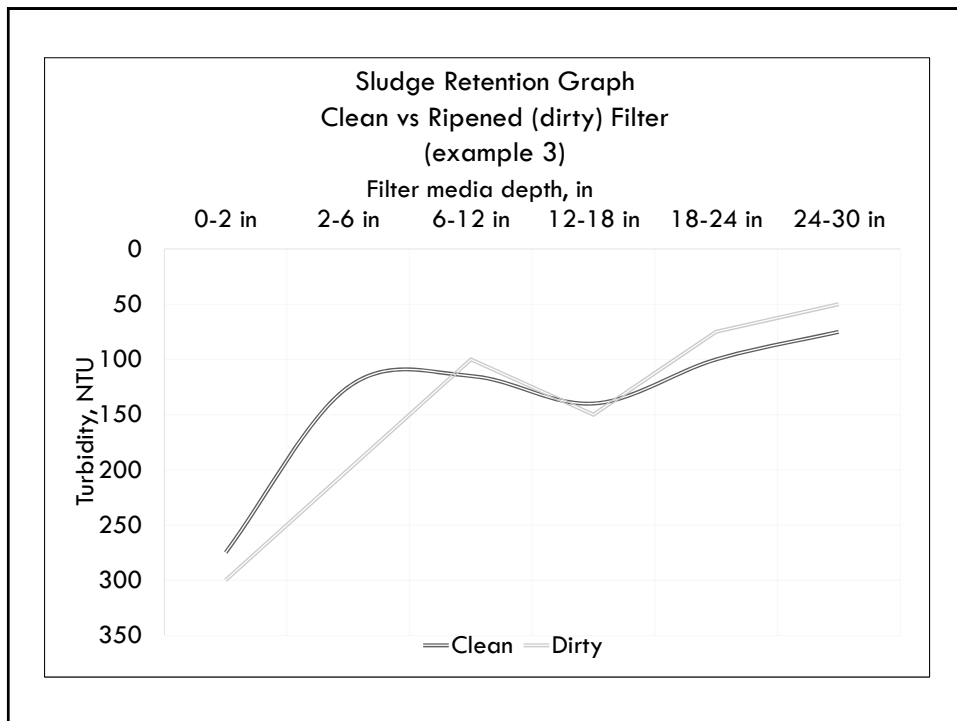
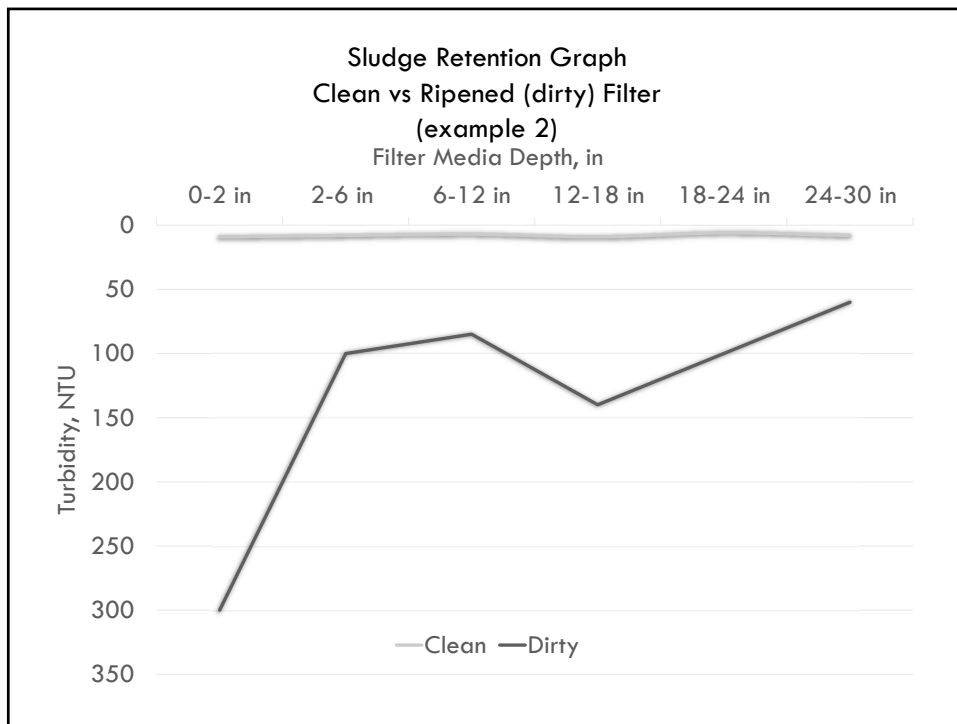


INTERPRETATION OF RESULTS

Sludge retention evaluation can be used to establish effectiveness of filter backwash procedure

Turbidity	Filter Media Condition
0-30 NTU	Clean - unripened filter • expect long periods of turbidity breakthrough
30-60 NTU	Clean - ripened filter • filter performance optimal
60-120 NTU	Slightly dirty • less than desirable, but should perform satisfactorily
>120 NTU	Mudball problems





SLUDGE RETENTION GRAPHS

Example 1

- Poor backwash due to insufficient bed expansion
- Only the top portion of the media came clean
- Since the lower media did not get expanded it did not get cleaned

Example 2

- Filter backwashed for too long - too clean

Example 3

- Filter was not backwash sufficiently; no cleaning was achieved



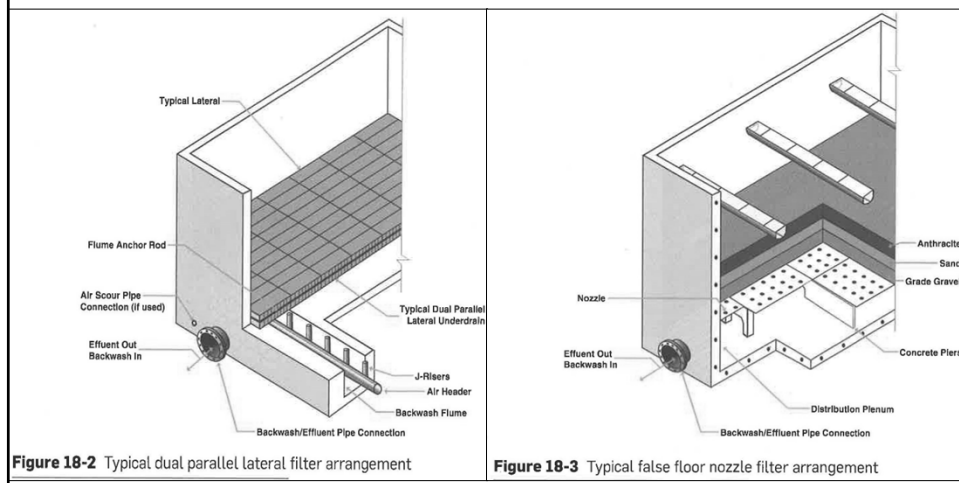
UNDERDRAIN INSPECTION | Chapter 18

UNDERDRAIN INSPECTION

Types and variations

- Manifold lateral system
- Fabricated self-supporting underdrain system
- False floor underdrain with nozzles

UNDERDRAIN SYSTEMS



UNDERDRAIN SYSTEMS

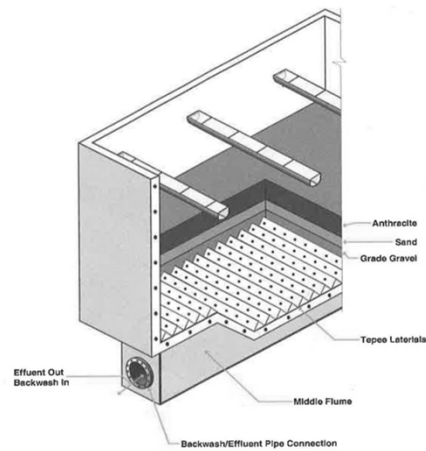


Figure 18-4 Typical folded plate lateral filter arrangement

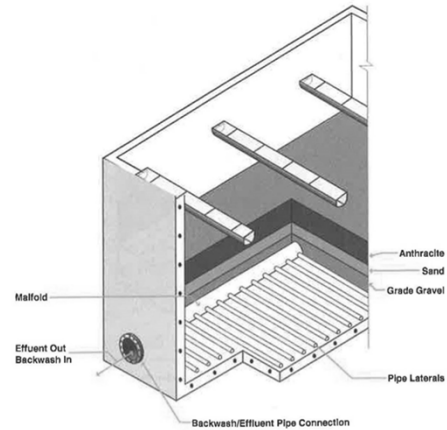


Figure 18-5 Typical pipe lateral filter arrangement

UNDERDRAIN SYSTEMS

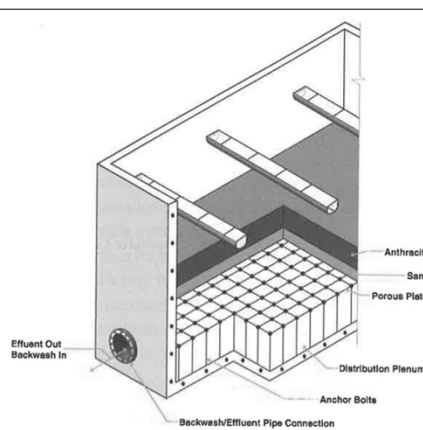


Figure 18-6 Typical porous plate filter arrangement

PRELIMINARY INSPECTION

Visual observation of filter for indications of underdrain failure

- Depressions in filter media
- Mudballs
- Unlevel media

Underdrain spot inspections can be performed with media in place

Identify potential problem areas to excavate

EQUIPMENT NEEDED

- Underdrain inspection form
- Excavation box (see diagram)
- Shovels
- Buckets
- Plastic tarp
- Safety
 - Ladder
 - Hard hat

PROCEDURE

Step 1. Backwash filter following SOP

Step 2. Use excavation box and place on surface of filter media

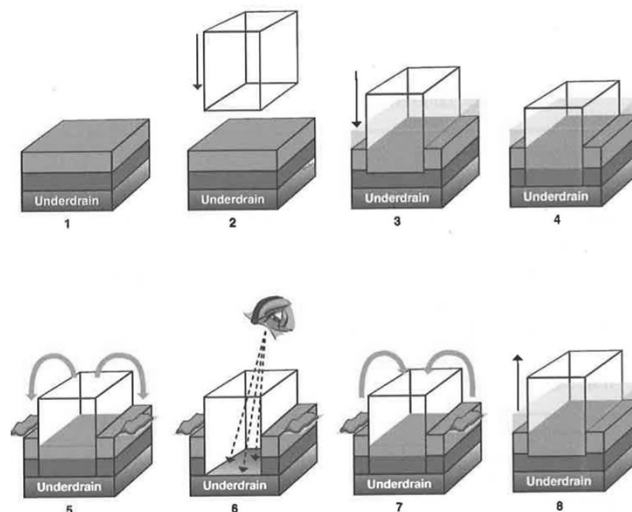
Step 3. Open backwash valve slightly to fluidize bed

Step 4. Push excavation box into fluidized bed until can go no further

Step 5. Stop backwash and drain filter media

Step 6. Remove media and support gravel from inside box and place each type of material in piles on separate tarps

EXCAVATION BOX

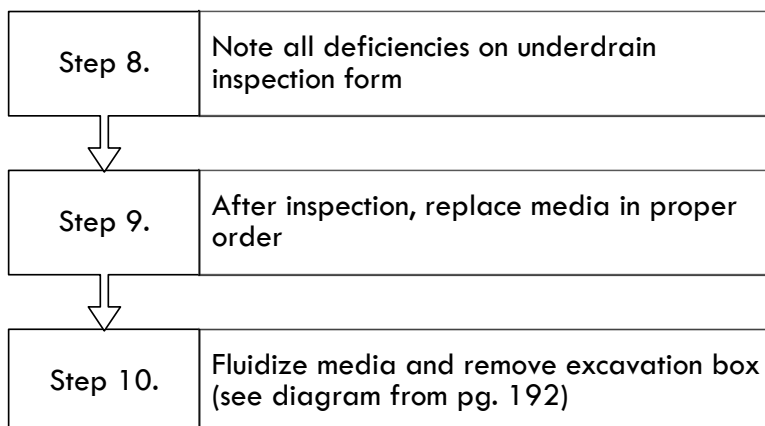


PROCEDURE

Step 7. Inspect underdrain

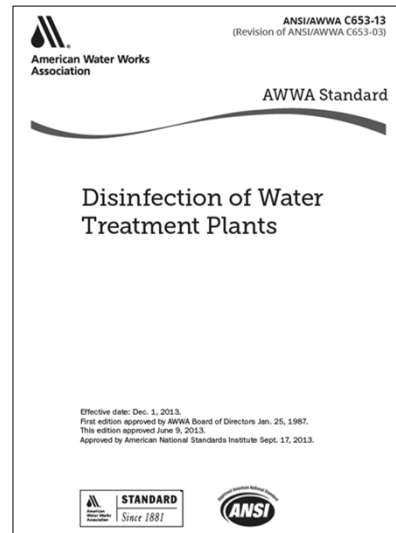
- Cracks in underdrain block or nozzles
- Holes in underdrain or floor
- Clogged underdrain block or nozzle inlets
 - Note type of material clogging inlet
- Grout failure
- Broken nozzles
- Structural failures

PROCEDURE



DISINFECTION

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 - Disinfection must take place before the filter is placed back into service
 - Follow AWWA Standard C653, Disinfection of Water Treatment Plants or the plant's pre-approved media-disinfection guidelines
- Granular activated carbon (GAC) cannot be disinfected, so special care should be used to protect against contamination



INTERPRETATION OF RESULTS

Clogs should be removed, preferably chemically

Replace broken nozzles, if applicable


Random evaluation can be problematic

Excavate all potential problem areas

- If problems found in all areas excavated, media should be removed for examination of entire underdrain
- If results mixed, areas that require work should be repaired

Section 5

Membrane Filtration

California State University, Sacramento	
	
	
<h1>Membrane Treatment Processes</h1>	

2
<h2>Objectives</h2> <ul style="list-style-type: none">• Introduction• Treatment Technologies• Operations• Operational Issues• Integrity Testing• Process Residuals• Electrodialysis

3

Introduction to Membrane Filtration



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4

Why Membrane Technology?

- **Regulatory**- the SWTR requires a higher level of turbidity and particulate removal. Membranes can consistently obtain that level of turbidity removal
- **Cost**- since the early 1990's the capital cost of membrane treatment has decreased. In addition, the implementation of innovative backwash and cleaning strategies have reduced the operational costs
- **Operational flexibility**- low pressure membrane filtration processes are highly flexible and can be used in conjunction with other processes to achieve specific treatment objectives. In addition, membrane facilities can be easy to operate because the process is not dependent on water chemistry or flow

5

Membranes: Science and Theory

- Pure water transport across a clean porous membrane is affected most by the trans-membrane pressure and the viscosity of the water
- **Trans-membrane pressure:** The force which drives liquid flow through a membrane filter. During filtration, the feed side of the membrane is under higher pressure than the permeate side. The pressure difference forces liquid through the membrane

6

Flux

- A flow or flowing
- Term used to describe the rate of water flow through the semipermeable membrane
- Expressed in gal/day/ft² of membrane surface area or gram/second/cm²
- There will always be a decline in flux with time due to membrane compaction
- “Flux decline” is a loss of water flow through a membrane due to compaction plus fouling

7

Temperature Effects

- Water behaves much like maple syrup
- The viscosity or resistance to flow of water is dependent on temperature
- The colder the water, the higher the viscosity
- Viscosity will affect membrane performance by either reducing the flux or by requiring an increase in trans-membrane pressure to keep the flux constant

8

Seasonal Effects

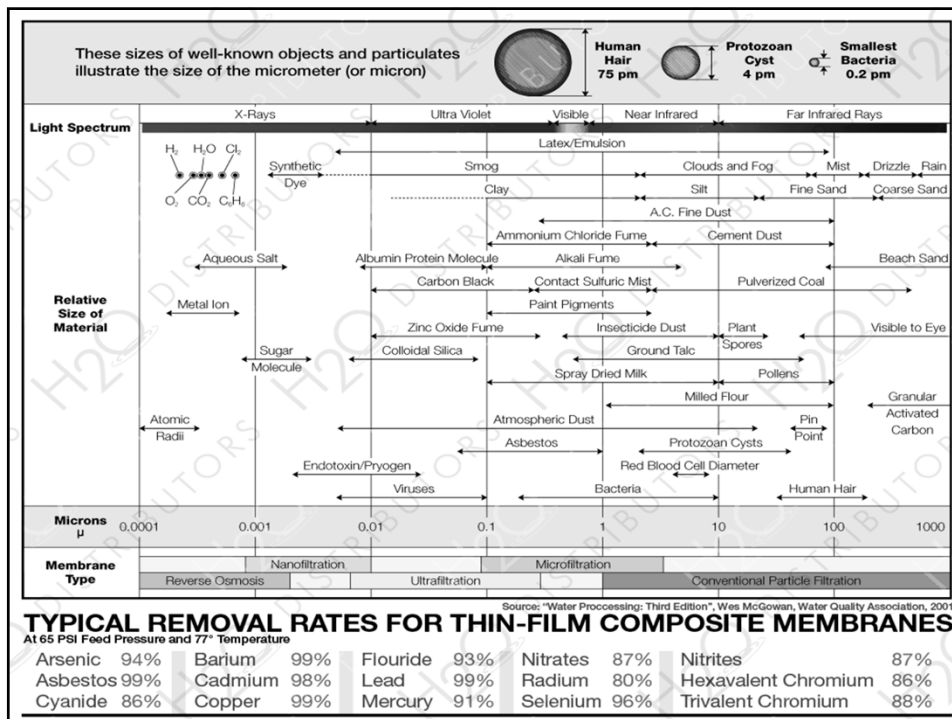
- Higher trans-membrane pressures may be required in the winter to offset the effect of temperature on the viscosity of the water
- Membrane fouling may also change with season and temperature
- Source water is variable, there is seasonal variation in the amounts of organics, metals, nitrates, etc



9

Membrane Treatment Technologies

- Contain very fine pore openings that allow water to pass through and block contaminants
- Types:
 - Microfiltration (MF)
 - Ultrafiltration (UF)
 - Nanofiltration (NF)
 - Reverse Osmosis (RO)
- Type of membrane depends on constituents to be removed



11

Membrane Filtration Treatment Technologies



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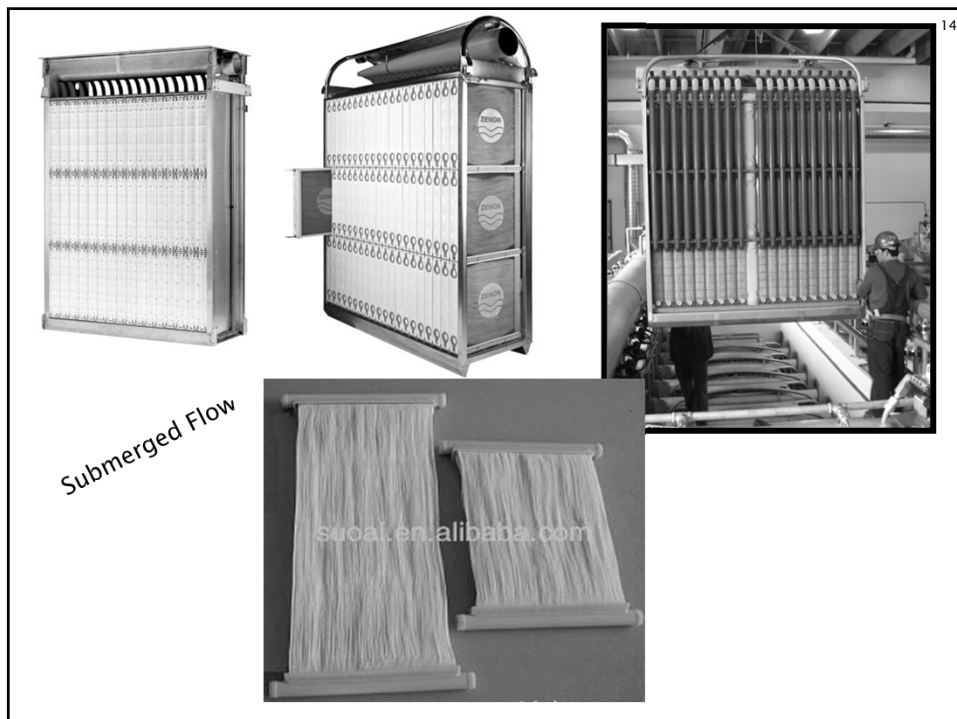
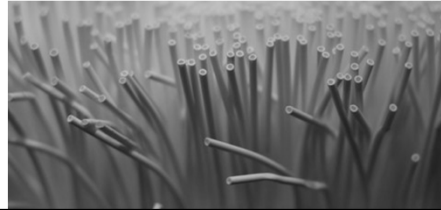
Membrane Treatment Technologies

- Microfiltration and ultrafiltration used in water treatment
 - Particles, sediments, algae, bacteria, and viruses
 - *Giardia* and *Cryptosporidium*
- Reverse osmosis used for desalination or demineralization and for home treatment units while nanofiltration can be used to reduce natural organic matter (DBP precursor)
 - Dissolved organic matter and dissolved contaminants such as arsenic, nitrate, pesticides, and radionuclides
 - Ions such as calcium, magnesium, sodium and chloride

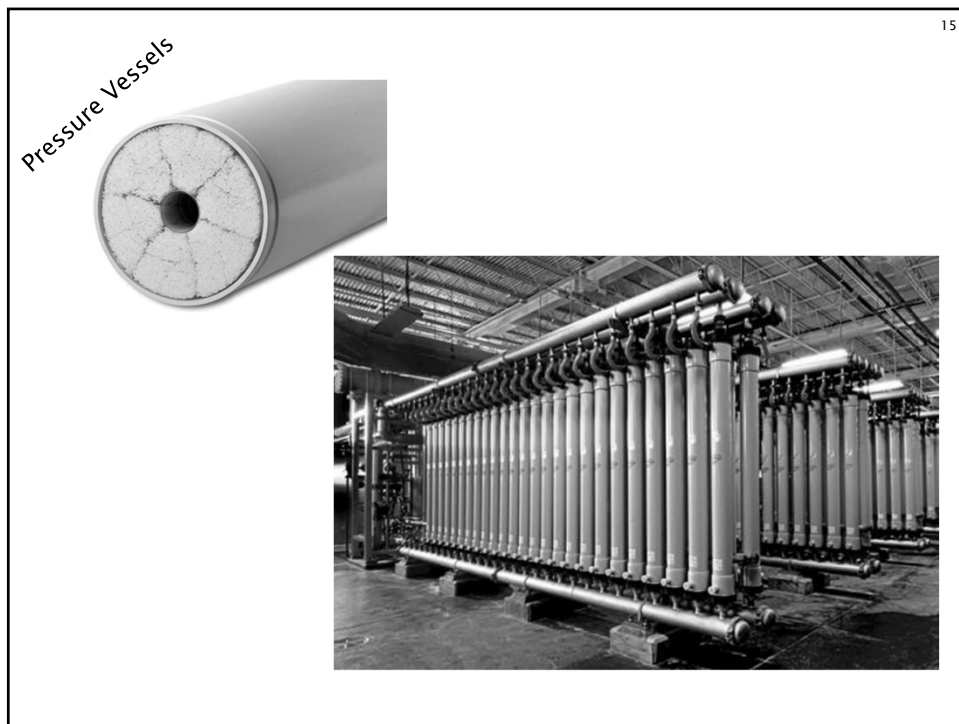
13

Membrane Filtration Units

- Membranes are hollow fibers
- Outside diameter of 0.5-2.0 mm
- Pressure vessels
 - Arranged in racks 4-12 inches in diameter and 3-18 ft long
 - May flow from outside in or from inside out
- Submerged flow
 - Modules suspended in basins of water to be treated
 - Flows from outside in



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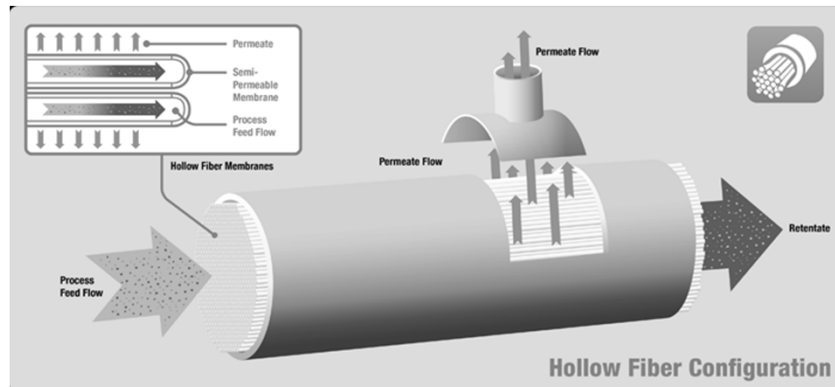
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Membranes

- Spiral wound
- Hollow fine fiber
- Tubular

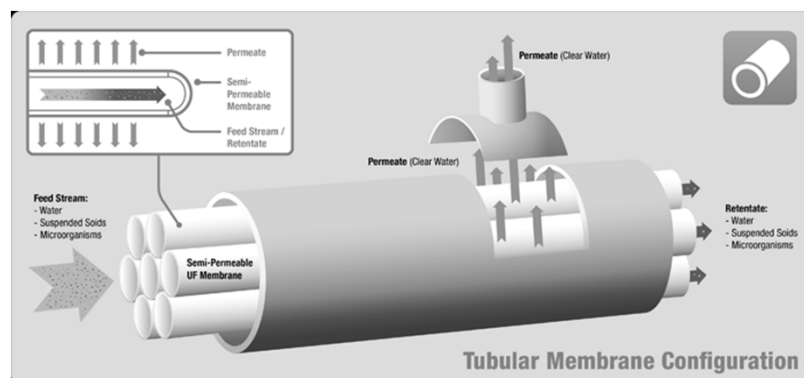
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Hollow Fiber Membrane



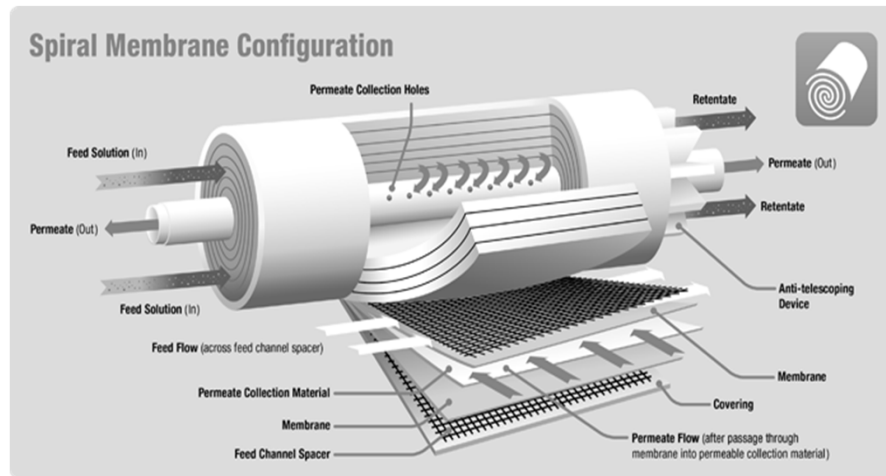
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Tubular Membrane



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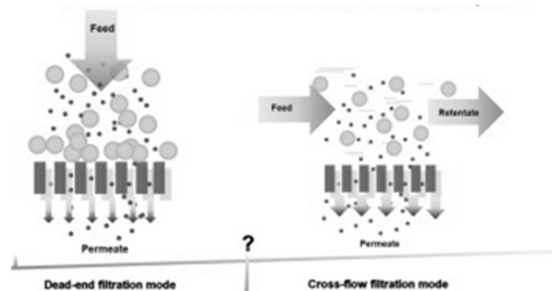
Spiral Wound Membrane



20

Membrane Flow Types

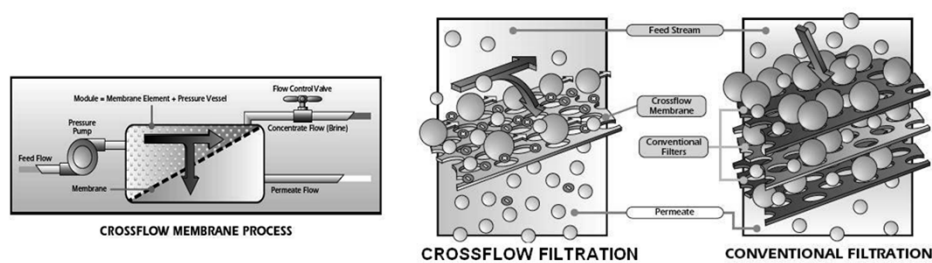
- Cross flow filtration
 - Water flows from inside fiber through the membrane and out of system
 - What does not flow through, flows out end of fiber as a waste stream
- Dead end filtration
 - Water may flow from inside out or outside in
 - Solids accumulate on membrane and are removed during backwash



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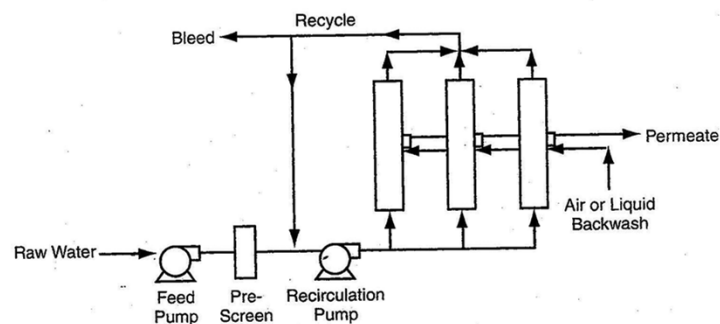
Crossflow Filtration

- In some cases, crossflow filtration is used
- The direction of the flow can help to prevent the deposition of materials on the membrane surface thereby reducing fouling



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System Configurations



Pressure driven system configuration with crossflow

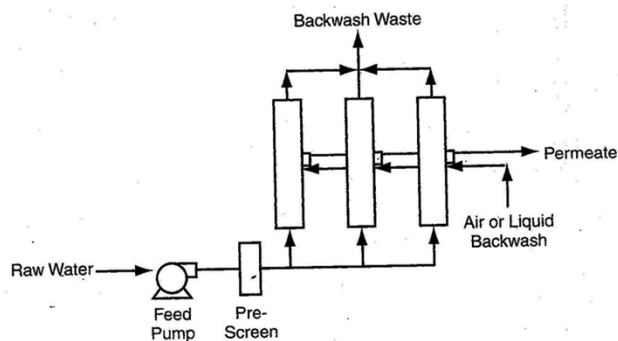
23

Crossflow

- Feed water is pumped with a crossflow tangential to the membrane
- The water that does not pass through the membrane is recirculated as concentrate and blended with the feed water
- Pressure on the concentrate side is conserved and deducted from the total head requirement
- A bleed stream can be used to control the concentration of solids in the recirculation loop
- Concentrate can be wasted at any time from the recirculation loop

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System Configuration



Pressure driven direct flow

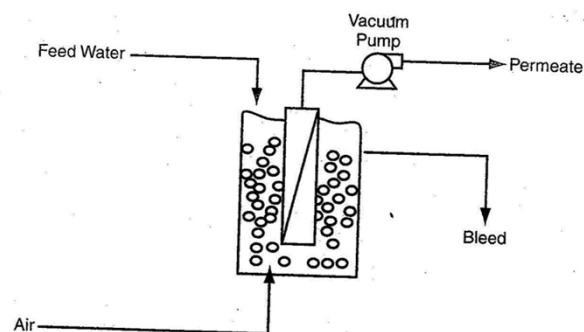
25

Direct Flow

- Also called dead-end or deposition mode
- Water is applied directly to the membrane
- All feed water passes through the membrane between backwashings
- There is 100% recovery of this water, however, some must be used for backwashing
- Considerable energy savings because recirculation is not required

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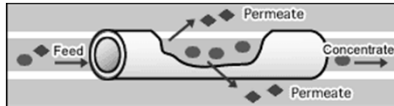
System Configuration



Direct flow submersible

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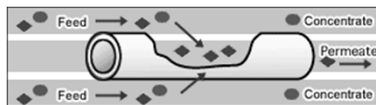
Inside-Out Filtration



- A high cross-flow velocity over the membrane surface prevents membrane fouling.
- Easier to backwash
- This makes inside-out filtration suitable for concentration and purification of highly concentrated solutions

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Outside-In Filtration



- Utilizing the larger area of the outer surface of the membrane fiber, the filtration load per unit area may be reduced
- Lower head loss through the module
- These features make this mode of operation well suited for high volume water clarification
- It is more difficult to backwash and control flow to the membrane
- Cleaning technique such as 'air-scrubbing' may be utilized

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Operations of Membrane Filtration



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Constant Pressure

Advantages:

- Feed pumps can be sized to maintain the constant pressure with simple on/off controls
- Energy requirements are constant

Disadvantages:

- Permeate flow will decrease over time due to membrane plugging prior to backwash
- Output of plant is reduced

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Constant Flux

Advantages:

- No over-sizing of the system is needed
- Out-put remains the same
- Most often used by full scale membrane plants

Disadvantages:

- Feed pressure must increase to maintain constant flux between backwashes
- Energy efficiency decreases with increased trans-membrane pressure

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Operations

Membrane Filtration

- Treatment is independent of pre-treatment conditions and raw water turbidity
- Pore size in membranes forms an effective barrier to cyst sized particles
- No need for a filter to waste step at the beginning of a filtration run

Conventional Filtration

- Requires optimized chemical pretreatment (coagulation, flocculation, sedimentation)
- Operators must adjust treatment for changing water conditions
- Giardia and Cryptosporidium may pass through filter
- Must filter to waste prior to returning to the filtration cycle after backwashing

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Operations

Membrane Filtration

- Increased turbidity may have no effect on performance, or it may cause a decline in flux or a decrease in time interval between backwashing and cleaning.
- Goal is to maintain finished water productivity; quality of the filtrate remains the same.

Conventional Filtration

- Increased turbidity will require additional coagulant to be added, or increased flocculation/settling, shorter filter runs, increased backwashing or may result in reduced finished water quality.
- Goal is to maintain finished water quality.

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Operations

Modes of Operation

- Filtration
- Air scrub
- Backwash
- Chemically enhanced backwash (some systems)
 - Aka enhanced flux maintenance (EFM)
- Chemical clean in place (CIP)
- Membrane Integrity Testing

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Operations

- Generally, filtration, backwash and air scrubbing are automatically controlled by the system based on operator selected points such as:
 - Trans-membrane pressure (TMP)
 - Flux rate or volume filtered
 - Filter run time
- Clean in place is usually selected manually.
- Integrity testing is conducted automatically or at operator selected intervals.

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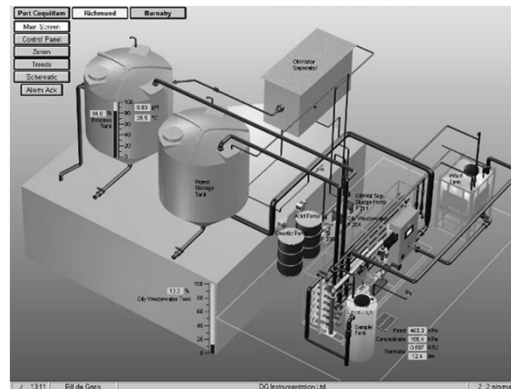
Operations

- Data Collection
 - Careful data collection and good recordkeeping are important to the successful long-term performance of membrane systems
 - Data should be collected as soon as the unit begins service and should include:
 - Flow of feed water, filtrate, and retentate
 - Temperature
 - Turbidity of feed and filtrate
 - Results of integrity testing
 - TMP

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Operations

- Most data is collected automatically using a SCADA system
- It is important to collect both pre and post cleaning data



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Reverse Osmosis Plant Operation

- Check cartridge filters
 - Should be replaced when head loss gets too high or effluent turbidity exceeds 1NTU
- Start up and check scale inhibitor feeding equipment
 - Use **sodium hexametaphosphate** as scale inhibitor
- Start chlorine feed if used to prevent biological fouling
- Start up and adjust acid feed system to keep feed water pH between 5 & 6
 - Protects membranes from damage due to hydrolysis

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RO Plant Operation

- Ensure system's automatic controls are set to proper parameters
- Adjust permeate and concentrate flow
- Check differential pressure across membrane unit
- Monitor performance
 - Flow measurements, product water quality, and various pressure indications

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Filtration Pretreatment

- **Prefiltration**
 - may be required to remove large particles that could plug the inlet to the fibers.
- **pH adjustment**
 - may be required to keep feed water in the optimum range for the membrane polymer type.
- **Adsorption and Coagulation**
 - coagulants and PAC can be used to prevent fouling of the membrane.
- **Pre-oxidation**
 - used to oxidize metals such as iron and manganese so that they do not form in the membrane or the permeate.

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Pump Requirements

- **Variable speed centrifugal:**
 - used to deliver raw water to membranes at the required flow and pressure (usually 20 -30 psi)
- **Permeate vacuum pump**
 - used for systems that operate under a vacuum, one dedicated to each membrane bank, sized to produce the permeate flow of each membrane bank
- **Recirculation pump**
 - used for inside-out crossflow configurations, one dedicated for each membrane bank
- **Backwash pump**
 - used for backwashing, may use liquid or gas medium

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Membrane Backwashing

- For most systems it is performed automatically
- Can be set for a run time, usually every 30-120 minutes
- Can also be set to backwash when a certain trans-membrane pressure is reached or when a certain amount of permeate has been produced
- The duration of backwash lasts from 1-5 minutes

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Backwashing

- The permeate collected in a reservoir is employed to backwash the membrane
- A liquid stream under pressure from a backwash pump dislodges solids from the surface of the membrane
- For submerged systems, backwashing occurs for 30 seconds every 15 minutes to several hours
- The backpulsing dislodges any deposition that has accumulated

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Post Treatment

- Disinfection: required by State and Federal Regulations
- Optional additions:
 - Fluoridation
 - Corrosion Control

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Cleaning

- When fouling materials can no longer be removed by backwashing, chemical cleaning is required
- Considerations include the cleaning and rinse volumes, temperature of cleaning water, reuse and disposal of chemicals
- Many different chemicals can be used including detergents, acids, bases, oxidizing agents and enzymes
- Chlorine is often used on PVDF membranes in concentrations from 2-2000 mg/L
- Heating the cleaning solution to 35-40°C can enhance cleaning effectiveness

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Cleaning Chemicals

- **Acids**
 - citric acid is most commonly used, it works well on inorganic contaminants such as iron. Other acids such as hydrochloric or sulfuric may be used
- **Bases**
 - caustic soda is the most commonly used, also good on inorganics
- **Oxidants**
 - free chlorine is very effective at removing organic contaminants
- **Surfactants**
 - release contaminants instead of dissolving them. Works well on PAC or if the membrane has a limited pH range

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Recordkeeping

- Water quality monitoring data
 - Turbidity and chlorine residual monitored continuously
- Water production data
 - Water levels, flow rates, hours of operations, and quality of water produced
- Maintenance information & tasks performed
- Calibration dates & procedures
- Cleaning dates & procedures
- Testing methods
- SDSs

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Recordkeeping

- Membrane filter maintenance and inspection
 - Transmembrane pressure
 - Filtration production by skid
 - Backwash occurrence
 - Membrane integrity testing using pressure decay testing
 - Membrane sonic testing
 - Membrane repair testing and fiber repairs

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Operational Issues in Membrane Filtration



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Components of Membrane Plant

1. Raw water source
 - Most are surface water
2. Raw water pump
 - Diverts water from the source into the treatment units
3. Pretreatment facility
 - Consists of chemical pretreatment processes to remove turbidity
4. Membrane filters
 - Remove particles, sediment, algae, bacteria and viruses
5. Backwashing
 - Based on three possible conditions:
 - time, flux, TMP

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Components of Membrane Plant

6. Backwash water treatment
 - Water from backwash requires treatment prior to discharge
7. Clean-in-place membrane regeneration system
 - Uses aggressive chemicals to regenerate membranes
8. Chemical feed systems
 - Disinfectants, CIP, corrosion control
9. CT chamber
 - Provides required contact time for disinfection
10. Clear well
 - Provides storage prior to distribution

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Components of Membrane Plant

11. Treated water pump station
 - Pumps treated water to distribution system
12. Standby engine generator
 - To provide power in the event of a power failure

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Troubleshooting

Problem	Cause	Corrective Action
Air compressor failure	<ul style="list-style-type: none"> • Mechanical failure inside unit • Belt failure • Oil pump leak 	<ul style="list-style-type: none"> • Rebuild failed compressor • Replace belt • Repair leak • Use portable air compressor
Raw water pump station failure	<ul style="list-style-type: none"> • Electronic failure of the uninterrupted power supply (UPS) 	<ul style="list-style-type: none"> • Bypass UPS • Conduct routine monthly checks of all plant UPS units
Computer lockup	<ul style="list-style-type: none"> • Central SCADA computer failure 	<ul style="list-style-type: none"> • Operate plant with only local control over plant operation • Hire an outside contractor to bring computer back to normal operating conditions

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Reductions in Membrane Productivity

Reductions in membrane productivity can result for a number of reasons including:

- Membrane Compaction
- Membrane Fouling
 - Inorganic fouling
 - Organic fouling
 - Biofouling

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Membrane Compaction

- Membrane compaction is a physical compression of the membrane
 - This compression results in a decrease in flux
 - The rate of compaction is directly proportional to an increase in temperature and pressure
- Compaction occurs naturally over time requiring a greater feed pressure
- Compaction is permanent and can occur quickly in membranes if operated at higher pressures for any extended period of time
- Usually, membrane compaction results in a few percent flux decline, and has strongest effect during the initial operating period

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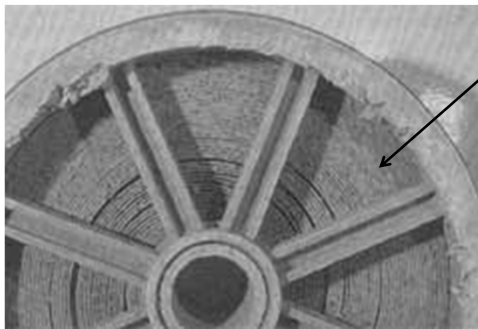
Membrane Fouling

- The cause of a loss of flow as a result of material being retained on the surface of the membrane or within its pores
- Reversible or irreversible
 - If reversible, flow may be recovered by backwashing and cleaning
- Material causing the fouling
 - Inorganic matter
 - Dissolved organic matter
 - Natural organic matter (most common)
- Means of the fouling
 - Pore adsorption, pore blocking or cake formation

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Inorganic Fouling

- Inorganic fouling can occur when inorganic particles such as silt, clay, iron, manganese, nitrates, etc are deposited on the surface of the membrane



Membrane fouled with inorganic material.

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Organic Fouling

- Organic fouling occurs when natural organic matter (NOM) in source water prevents flux across the membrane by plugging pores in the membrane



A membrane severely fouled by organics

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Biofouling

- Biofouling occurs when microorganisms adhere to the membrane surface and begin to grow colonies on or in the membrane
 - The microbes will eventually obstruct the flow through the membrane.

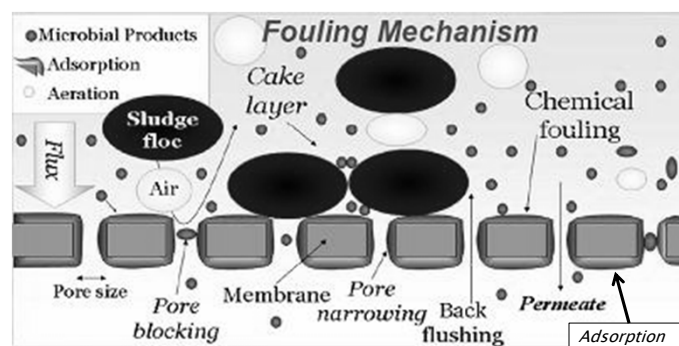


Extreme biofouling of membrane.

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Fouling Mechanisms

- **Pore Adsorption**
 - Occurs when particles smaller than the pore deposit themselves on the pore walls which reduces the effective size of the pores

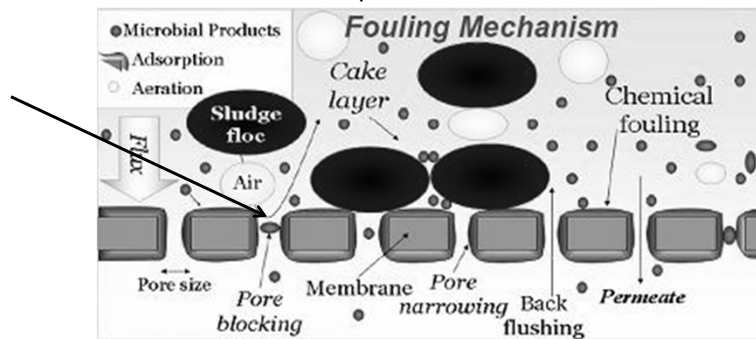


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Fouling Mechanisms

- **Pore Blocking**

- occurs when particles as large as the pore become lodged in the pore and block the passage
- the effective number of pores is reduced

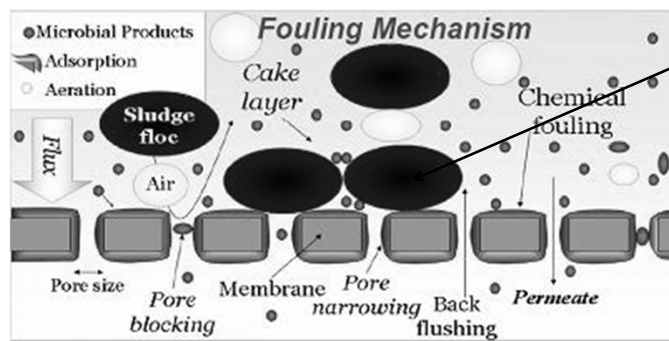


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Fouling Mechanisms

- **Cake Formation**

- This occurs when particles too large to enter the pores become deposited on the surface of the membrane
- Cake formation results in a reduced flux across the membrane



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Troubleshooting

Condition	Ideas to Consider
High turbidity in filtrate	Conduct integrity test
	If integrity test indicates no broken fibers or leaks, verify turbidity reading
	Measure turbidity in a grab sample
	Clean and calibrate turbidimeter, look for problems (air bubbles)

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Troubleshooting

Condition	Ideas to consider
High rate of fiber breakage	Check pressures and water hammer potential being applied during operating cycles. Inaccurate pressure can result in damage during a backwash or integrity test.
	Check for exposure to highly concentrated chemicals, evaluate quality of CIP and CEB (chemically enhanced backwash) chemicals
	Check for exposure to extreme temperatures
	Consider the age of the membranes
	Have the integrity and strength of membranes evaluated by the manufacturer (membrane autopsy)
	If fibers are not old, consider a warranty claim
	Old or improperly operated membranes may become brittle, they need to be operated wet.

Troubleshooting	
Condition	Ideas to Consider
Interval between cleanings is too short	Verify that the data are normalized for temperature, flux may be too high for the application
	Raw water quality may have changed
	Evaluate pretreatment processes, mishandled polymer can result in significant irreversible flux loss.
	Evaluate backwash and chemically enhanced backwash (CEB) procedures, and the chemicals used.
	Consider the effects of pH, may cause aluminum scale on membrane if alum is used in pretreatment
	Evaluate CIP procedures with manufacturer and engineers, compare with other utilities
	Chemically enhanced backwash if not already in use may increase the interval between CIPs.

Troubleshooting	
Condition	Ideas to consider
CIP does not return unit to baseline	Check normalized clean water resistance and permeability values
	Evaluate CIP procedure, more aggressive cleaning may be needed (higher temp, stronger chemical concentration if compatible with membrane)
	Consider changing the order of chemicals (acid before caustic, etc)
	Consider the effects of pH, may cause aluminum scale on membrane if alum is used in pretreatment
	Evaluate CIP procedures with manufacturer and engineers, compare with other utilities
	Consider using soft water for CIP solutions

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Integrity Testing of Membrane Filters



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**Environment &
Conservation**

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Membrane Integrity Testing

- One of the most critical aspects of employing membrane technology is integrity testing
- Integrity testing ensures that the membranes are an effective barrier between the feed water and the permeate being produced

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Integrity Testing

There are several methods that can be used to monitor membrane integrity including:

- Turbidity monitoring
- Particle counting
- Particle monitoring
- Biological monitoring
- Air pressure decay testing
- Diffusive air flow testing
- Water displacement testing
 - Bubble testing
 - Sonic wave sensing
 - Visual inspection

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Air Pressure Decay Testing

- The membrane module is pressurized to approximately 15 psi from the feed side
- Minimal loss of held pressure (usually less than 1 psi every 5 minutes) at the filtrate side indicates a passed test
- A significant decrease of the held pressure indicates a failed test

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Visual Inspection

- If a pressure-based integrity test is used, visual inspection can be conducted simultaneously by watching the fibers for bubbles escaping
- Often the module may have to be removed from the housing so that visual inspection can be performed



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Bubble Testing

- Bubble testing can identify a fiber or seal location that is leaking in a membrane module
- This test is usually run after the compromised module is identified by another monitoring method such as air pressure decay or a sonic sensor
- Basically, the module is submerged while air is passed through it, bubbles formed by escaping air identify the location of the leaking fiber
- The leaking fiber is either sealed using epoxy glue or by inserting a pin of the same diameter into the inlet



73	
Troubleshooting	
Condition	Ideas to consider
Failed Integrity Test	Verify readings
	Determine if membranes are fully wetted or have become hydroscopic
	Locate and isolate modules with flaws or leaking seals or O rings
	Conduct new integrity test with problem modules removed to make sure all the problems have been found
	Determine the nature of the failure
	Repair flawed module and return to service
	Conduct new integrity test to make sure the problem is resolved

74	
<h1>Process Residuals of Membrane Filtration</h1>	
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75

Process Residuals

- Waste characteristics depend on the source water being treated
- Waste usually contains inorganic and organic colloids, pathogens, and turbidity
- If coagulants, PAC or other pretreatment chemicals are used the residual is similar to that produced by conventional treatment plants
- Chemical cleaning waste has a different composition and usually a small volume compared with the concentrate and backwash residuals

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Process Residuals

Methods of disposal include:

- Surface Water Discharge
- Sewer Discharge
- Land Application
- Recycling

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Process Residuals

Surface Water Discharge

- Surface water discharge must meet the requirements of a site specific NPDES permit
- May require treatment prior to surface water discharge
- For most installations, a settling basin or lagoon will suffice



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Process Residuals

Sewer discharge-

- Most commonly used method of backwash waste disposal
- Sewer disposal of backwash waste is controlled by the receiving wastewater treatment plant's NPDES permit and available sewer capacity
- May not be feasible at all locations



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Process Residuals

Land Application

- Includes percolation ponds or lagoons, spray irrigation and leach fields
- May require chemical neutralization
- Periodic removal of accumulated solids from lagoons may be required



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Process Residuals

Recycling

- At large installations recycling is accompanied by some type of settling process to concentrate solids
- Backwash water and cleaning water are sent to a clarifier or settling basin
- The supernatant is collected off the surface of the settling basin and mixed with feed water



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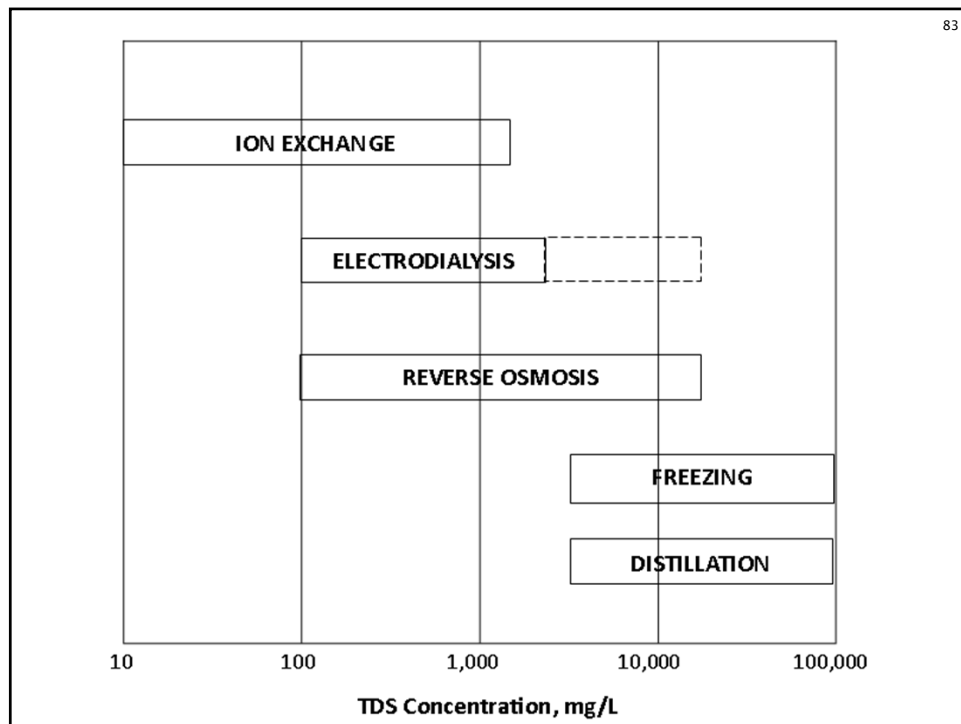
Electrodialysis



82

Demineralization

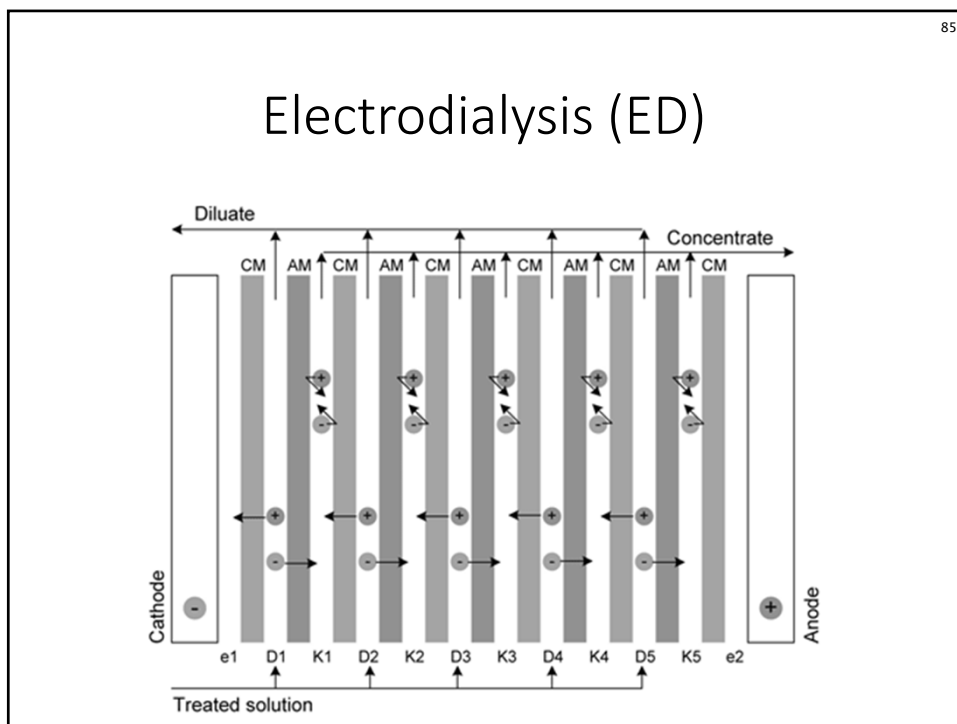
- Process that removes dissolved minerals (salts) from water
 - Primarily used to remove dissolved inorganic materials (TDS)
- Two classes
 - Phase change, i.e. freezing or distillation
 - Non-phase change, i.e. reverse osmosis, electrodialysis, and ion exchange
- Water industry mainly uses non-phase change method



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Electrodialysis (ED)

- Water flows between alternating cation-permeable and anion-permeable membranes
- Membranes assembled into stacks
- Spacers contain the water streams and direct the flow across the membranes faces
- Several hundred membranes and their spacers between a set of electrodes form a membrane stack



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Electrodialysis (ED)

- Occurs in 10-20 seconds
- Percent mineral removal depends on
 - Water temperature
 - Type and amount of ions present
 - Water flow rate
 - Stack design
- 25-40% removal
- 1-6 stacks/stages
- Operates at temperatures up to 110°F
 - Efficiency increases as temperature increases

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Electrodialysis (ED)

- Advantages
 - Well developed technology
 - Efficient removal of most inorganics
 - Waste brine contains only salts plus a small amount of acid used for pH control
- Most common problem is scaling (fouling) by organic and inorganic material damaging or destroying membranes
 - Feed acid to the concentrate to keep the Langelier Index negative

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Electrodialysis Reversal (EDR)

- System reverses DC current direction and flow path of dilution and concentrating streams every 15 minutes
- Electrodes reverse by switching polarity of cathodes and anodes
- Stream flow paths exchange source every 15 minutes
- This makes it possible to prevent scale formation on membranes without additional chemicals

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Principles of Electrodialysis

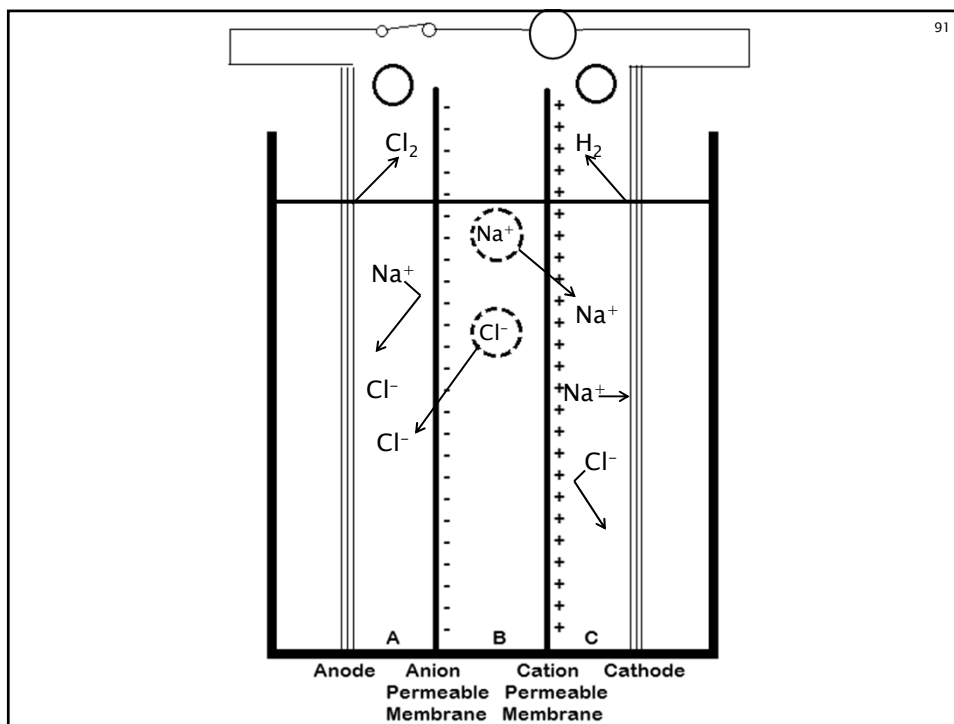
- Ion – charged molecule
- Anion – negatively charged ion
- Cation – positively charged ion
- Anode – positive electrode
- Cathode – negative electrode

Remember: Opposites attract
Likes repel

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Principles of Electrodialysis

- Using the properties of ions to purify water
 - Cations will move toward cathode and anions will move toward anode
 - Install proper barriers and isolate a purified zone
- Place these “barriers” into a solution to form three compartments to demineralize the central compartment
- Two types of membranes
 - Cation-permeable membranes
 - Permit only the passage of cations
 - Anion-permeable membranes
 - Permit only the passage of anions

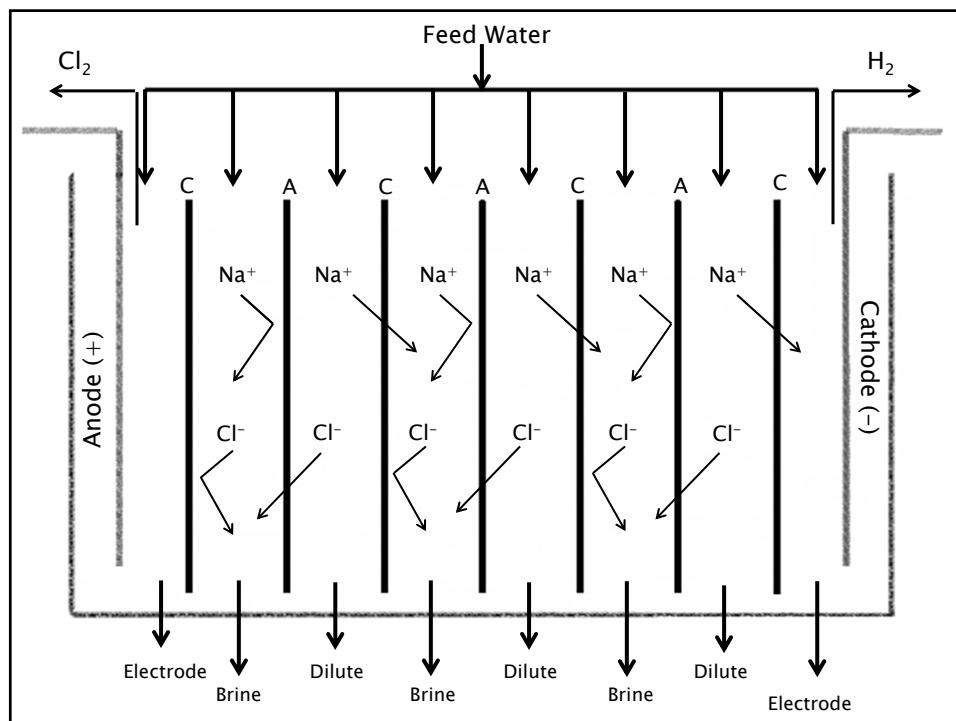


Process

- 1. Na^+ from compartment A cannot pass through anion-permeable membrane (2) into compartment (B)
- 2. Cl^- from compartment A reacts at the anode (1) to give off chlorine gas
- 3. Na^+ from compartment B passes through cation-permeable membrane (3) into compartment C
- 4. Cl^- from compartment B passes through anion-permeable membrane (2) into compartment A

Process

- 5. Na^+ from compartment C reacts at the cathode to give off hydrogen gas and hydroxyl ions (OH^-)
- 6. Cl^- from compartment C cannot pass through the cation-permeable membrane (3) into compartment B
- End result: demineralized central compartment



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Multi-Compartment Unit

- A = anion-permeable principle
- C = cation-permeable principle
- Ions will move from compartments bounded by an anion-permeable membrane on the left and a cation-permeable membrane on the right into the adjacent compartment
- Compartments losing salt are “dilute”
- Compartments receiving salt are “brine”
- Chlorine gas is evolved at the cathode
- Hydrogen gas is evolved at the anode

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Parts of an ED Unit

- Pretreatment
 - Includes removal of suspended or dissolved solids, iron, manganese, or chlorine residual
 - Can be accomplished with cartridge filter
- Pumping equipment
 - Use only for circulation through stack
 - 50-75 psi
- DC power supply
 - AC is converted by rectifier to DC which is applied to electrodes
 - Control module reverses current every 15-30 minutes

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Parts of an ED Unit

- Membrane stack
 - Comprised of many stacked pieces: half are membranes, half are spacers that alternate
 - 2 membranes or 2 spacers should never occur together
 - 1 stack = 1 demineralization stage
 - Cell pairs consist of one anion-permeable membrane, one cation-permeable membrane, and two intermembrane spacers
- Chemical flush system
 - 5% HCl (hydrochloric acid) and 5% salt solution that has caustic soda added are used to periodically flush membrane stack in a CIP process

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Feedwater

- If iron concentration > 0.3 mg/L, needs to be removed by pretreatment
- Should be free of bacteria to prevent biological membrane fouling
- Control of pH important due to corrosion control in piping and plumbing equipment
- Cannot contain any chlorine residual
 - If prechlorinate, water must be dechlorinated before ED unit

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Feedwater

- Do not operate ED unit if feed water contains any of the following:
 - Chlorine residual of any concentration
 - Hydrogen sulfide of any concentration
 - Calgon or other hexametaphosphates in excess of 10 mg/L
 - Manganese in excess of 0.1 mg/L
 - Iron in excess of 0.3 mg/L

Maintenance

- Daily
 - Fill out log sheet
 - Verify that electrodes are bumping and flowing properly
 - Inspect stacks for excess external leakage
 - Greater than 10 gal/hr/stack
 - Check pressure drop across the cartridge filter and change the cartridges whenever the pressure drop reaches 10 psi
- Weekly
 - Voltage probe the membrane stacks
 - Check the oil level on pumps fitted with automatic oilers
 - Inspect all piping and skid components for leaks
 - Twice per week, measure all electrode waste flows

Membrane Filtration Vocabulary

Asymmetric – Having a varying consistency throughout (e.g. a membrane that varies in density or porosity across its structure).

Backpulse – A very short-duration backwash.

Backwash – The intermittent waste stream from a microfiltration or ultrafiltration membrane system; also, a term for a cleaning operation that typically involves periodic reverse flow of clean water and/or air from the filtrate side to the feed side to remove foulants accumulated at the membrane surface.

Bank – A group of pressure vessels that share common valving and that can be isolated as a group for testing, cleaning, or repair; synonymous with the terms train, skid, rack and membrane unit.

Biofouling – Membrane fouling that is attributed to the deposition and growth of microorganisms on the membrane surface and/or the adsorptive fouling of secretions of microorganisms.

Bleed – The continuous waste stream from a microfiltration or ultrafiltration system operated in a crossflow mode (synonymous with the terms reject and concentrate).

Cartridge – A type of module consisting of a disposable backwashable or nonbackwashable filter element contained in an external casing.

Chemical Cleaning (also, Clean-In-Place or CIP) – The periodic application of a chemical solution (or series of solutions) to a membrane unit for the intended purpose of removing accumulated foulants and thus restoring permeability and resistance to baseline levels; a commonly used term for in situ chemical cleaning.

Crossflow – The application of water at high velocity tangential to the surface of a membrane to maintain contaminants in suspension.

Differential Pressure – A pressure drop across a membrane module or unit from the feed inlet to concentrate outlet.

Fiber – A single hollow fiber or hollow fine fiber.

Filtrate – The water produced from a filtration process.

Flux – The throughput of a pressure-driven membrane filtration system, expressed as flow per unit of membrane area.

Foulant – Any substance that causes fouling.

Fouling – The gradual accumulation of contaminants on a membrane surface or within a porous membrane structure that inhibits the passage of water, therefore decreasing productivity.

Hydrophilic – The water-attracting property of membrane material.

Hydrophobic – The water-repelling property of membrane material.

Inside-out – A flow pattern associated with hollow fiber membranes in which the feedwater enters the inside of the fiber and is filtered as it passes through the lumen wall to the outside of the fiber.

Log Removal – The filtration removal efficiency for a target organisms, particulate, or surrogate expresses as \log_{10} .

Lumen – The center or bore of a hollow fiber membrane.

Microfiltration (MF) – A pressure-driven membrane filtration process that typically employs hollow fiber membranes with a pore size range of approximately 0.10 – 0.5 μm .

Nanofiltration (NF) – A pressure-driven membrane separation process that employs the principles of reverse osmosis to remove dissolved contaminants from water; typically applied for membrane softening or the removal of dissolved organic contaminants.

Outside-In – A flow pattern associated with hollow fiber membranes in which the feedwater is filtered through the lumen wall as it passes from the outside of the fiber to the inside where the filtrate is collected.

Reverse Osmosis (RO) – The reverse of the natural osmosis process, i.e. the passage of a solvent (e.g. water) through a semipermeable membrane from a solution of higher concentration to a solution of lower concentration against the concentration gradient, achieved by applying pressure greater than the osmotic pressure to the more concentrated solution; also, the pressure-driven membrane separation process that employs the principles of RO to remove dissolved contaminants from water.

Scaling – The precipitation or crystallization of salts on a surface (e.g. on the feed side of a membrane).

Ultrafiltration (UF) – A pressure-driven membrane filtration process that typically employs hollow fiber membranes with a pore size range of approximately 0.01-0.05 μm .

Membrane Vocabulary

A. atm	J. Enzymes	T. Natural organic matter
B. Colloids	K. Feedwater	U. Osmosis
C. Conductance	L. Flux	V. Permeate
D. Cross-flow filtration	M. Fulvic acid	W. Reverse osmosis
E. Dead-end filtration	N. Humic substances	X. SCADA
F. Demineralization	O. Hydrolysis	Y. Salinity
G. Disinfection by-product	P. Material Safety Data Sheets	Z. Sequestration
H. Dissolved organic carbon	Q. Membrane fouling	AA. Total dissolved solids
I. Dissolved organic matter	R. Microfiltration	BB. Ultrafiltration
	S. Nanofiltration	

- _____ 1. Natural organic matter resulting from partial decomposition of plant or animal matter and forming the organic portion of soil.
- _____ 2. Humic substances composed of humic and fulvic acids that come from decayed vegetation.
- _____ 3. A type of membrane filtration where the water being filtered flows across the surface of the membrane to keep the particle buildup and fouling to a minimum.
- _____ 4. The relative concentration of dissolved salts, usually sodium chloride, in water.
- _____ 5. That portion of the organic matter in water that passes through a 0.45 µm pore-diameter filter.
- _____ 6. A chemical complexing of metallic cations with certain inorganic compounds.
- _____ 7. A pressure-driven membrane filtration process that separates particles down to approximately 0.1 µm diameter from influent water using a sieving process.
- _____ 8. A flowing or flow.
- _____ 9. A contaminant formed by the reaction of disinfection chemicals with other substances in the water being disinfected.
- _____ 10. A rapid method of estimating the dissolved solids content of a water supply. Indicates capacity of sample to carry an electric current.
- _____ 11. A pressure-driven membrane filtration process that separates particles down to approximately 0.01 µm diameter from influent water using a sieving process.
- _____ 12. A type of membrane filtration where the water being filtered flows through the membrane, but there is no wastestream from the system.
- _____ 13. Very small, finely divided solids that remain dispersed in a liquid for a long time due to their small size and electrical charge.
- _____ 14. All of the dissolved solids in water.

- _____ 15. To penetrate and pass through, as water penetrates and passes through soil and other porous materials.
- _____ 16. A complex organic compound that can be derived from either soil or water.
- _____ 17. The application of pressure to a concentrated solution, which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane.
- _____ 18. Organic or biochemical substances that cause or speed up chemical reactions.
- _____ 19. A treatment process that removes dissolved minerals (salts) from water.
- _____ 20. Supervisory Control And Data Acquisition system.
- _____ 21. The cause of a loss of flow through a membrane as a result of material being retained on the surface of the membrane or within the membrane pores.
- _____ 22. The water that is fed to a treatment process; the water that is going to be treated.
- _____ 23. That portion of the organic carbon in water that passes through a 0.45 μm pore-diameter filter.
- _____ 24. The passage of a liquid from a weak solution to a more concentrated solution across a semipermeable membrane.
- _____ 25. A chemical reaction in which a compound is converted into another compound by taking up water.
- _____ 26. The abbreviate for atmosphere. One atmosphere is equal to 14.7 psi or 100 kPa.
- _____ 27. A document that provides pertinent information and a profile of a particular hazardous substance or mixture.
- _____ 28. A pressure-driven membrane filtration process that separates particles down to approximately 0.002 to 0.005 μm diameter from influent water using a sieving process.

Answers

- | | | |
|-------|--------|-------|
| 1. N | 11. BB | 21. Q |
| 2. T | 12. E | 22. K |
| 3. D | 13. B | 23. H |
| 4. Y | 14. AA | 24. U |
| 5. I | 15. V | 25. O |
| 6. Z | 16. M | 26. A |
| 7. R | 17. W | 27. P |
| 8. L | 18. J | 28. S |
| 9. G | 19. F | |
| 10. C | 20. X | |

Section 6

Pumps

California State University: Sacramento



Department of
**Environment &
Conservation**

Pumps

1

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Objectives

- Classification of Pumps
- Positive Displacement Pumps
- Velocity Pumps
- Parts of a Centrifugal Pumps
- Pump Operations

3

Classification of Pumps



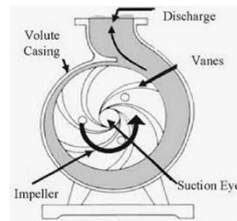
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Necessity Of Pumps

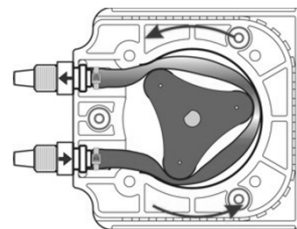
- Pumps are required when gravity cannot supply water with sufficient pressure to all parts of the distribution system
- Pumps account for the largest energy cost for a water supply operation

Types of Pumps

- Velocity Pumps



- Positive-Displacement Pumps



Types of Pumps

- Positive-Displacement Pumps
 - Metering pumps
 - sometimes used to feed chemicals
 - Piston pump
 - Screw pump
- Velocity Pumps
 - Vertical turbine
 - Centrifugal

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Positive Displacement Pumps



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Positive-Displacement Pumps

- Chemical feed pumps
- Delivers a constant volume with each stroke
- Less efficient than centrifugal pumps
- **Cannot operate against a closed discharge valve**
- Types:

External Gear Pump



Gerotor Pump



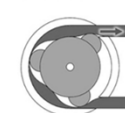
Lobe Pump



Internal Gear Pump



Peristaltic Pump



Vane Pump

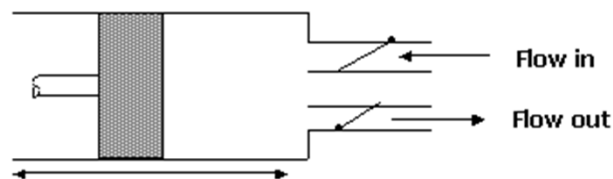


Positive-Displacement Pumps

- Metering pumps – most common type of solution feeder
- Delivers precise volume of solution with each stroke or rotation
- Typically have variable-speed motor that can be adjusted to control chemical flow

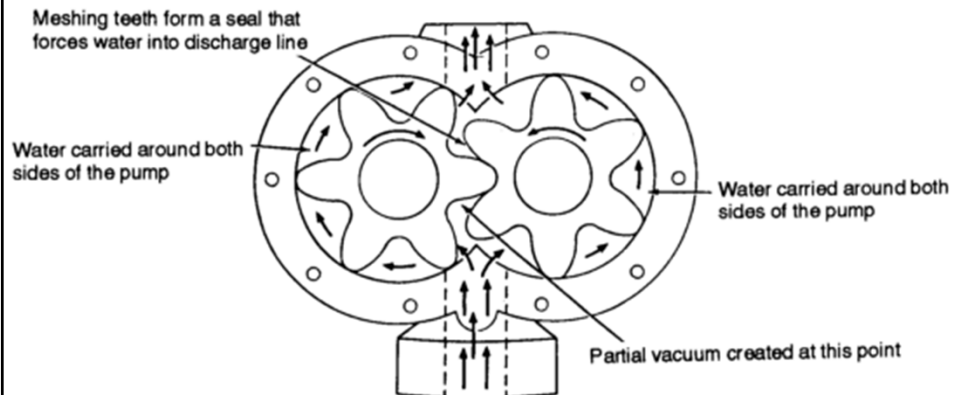
Reciprocating Pump

- aka Piston Pump
- Piston moves back and forth in cylinder, liquid enters and leaves through check valves



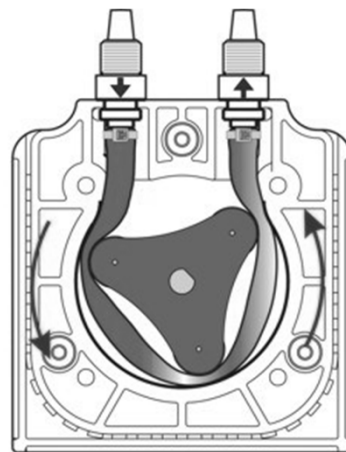
Rotary Pumps

- Uses lobes or gears to move liquid through pump



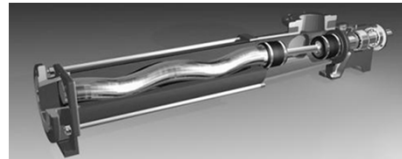
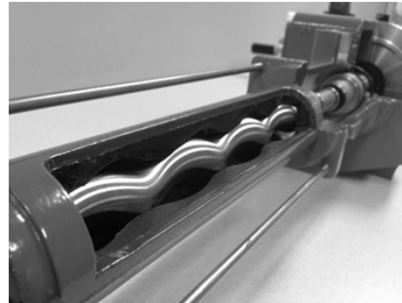
Peristaltic Pumps

- Fluid to be pumped flows through flexible tube inside a pump casing
- Rotor inside turns and compresses the tube
- Rotor forces fluid through tube



Screw Pumps

- aka progressive cavity pumps
- Screw pumps are used to lift wastewater to a higher elevation
- This pump consists of a screw operating at a constant speed within a housing or trough
- The screw has a pitch and is set at a specific angle
- When revolving, it carries wastewater up the trough to a discharge point

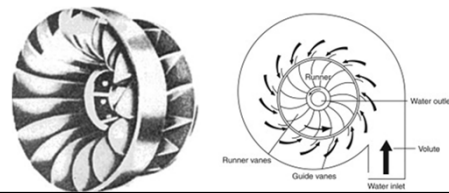


Velocity Pumps



Velocity Pumps

- Centrifugal (Volute) Pumps
 - Spinning impeller or propeller accelerates water to high velocity in pump casing (or volute)
 - High velocity, low pressure water converted to high pressure, low velocity water
- Turbine Pumps
 - Velocity head is converted to pressure head by diffuser guide vanes



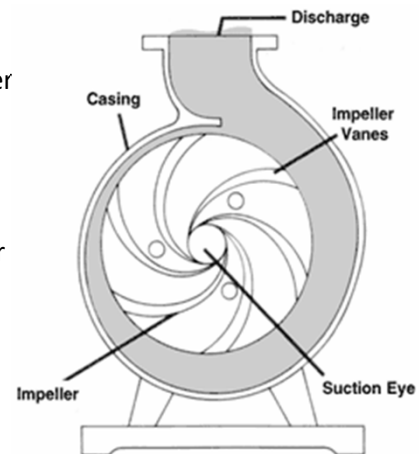
Velocity Pump Design Characteristics

- Axial - flow designs
 - Propeller shaped impeller adds head by lifting action on vanes
 - Water moves parallel to pump instead of being thrown outward
 - High volume, but limited head
 - Not self-priming



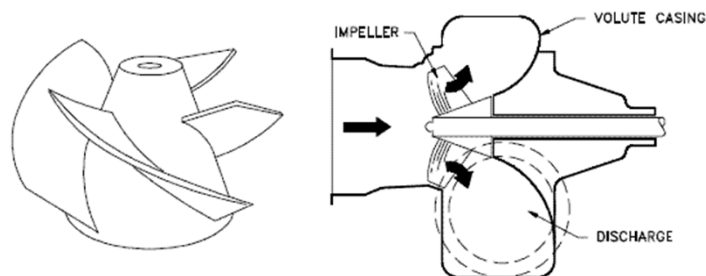
Velocity Pump Design Characteristics

- Radial flow designs
 - Water comes in through center (eye) of impeller
 - Water thrown outward from impeller to diffusers that convert velocity to pressure
 - The discharge is perpendicular to the pump shaft
 - Centrifugal or Turbine



Velocity Pump Design Characteristics

- Mixed - flow designs
 - Has features of axial and radial flow
 - Works well for water with solids
 - Turbine



Centrifugal Pump

- Basically, a very simple device: an impeller rotating in a casing
- The impeller is supported on a shaft, which in turn, is supported by bearings
- Liquid coming in at the center (eye) of the impeller is picked up by the vanes and by the rotation of the impeller and then is thrown out by centrifugal force into the discharge

Centrifugal Pumps

- Volute-casing type most commonly used in water utilities
- Impeller rotates in casing - radial flow
- Single or multi-stage
- By varying size, shape, and width of impeller, a wide range of flows and pressures can be achieved

Advantages of Centrifugal Pumps

- Wide range of capacities
- Uniform flow at a constant speed and head
- Low cost
- Ability to be adapted to various types of drivers
- Moderate to high efficiency
- No need for internal lubrication



Disadvantages of Centrifugal Pumps

- Efficiency is limited to very narrow ranges of flow and head
- Flow capacity greatly depends on discharge pressure
- Generally, no self-priming ability
- Can run backwards if check valve fails and sticks open
- Potential impeller damage if pumping abrasive water

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Parts of a Centrifugal Pump



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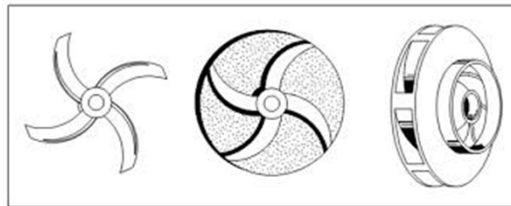
Let's Build a Centrifugal Pump

- First we need a device to spin liquid at high speeds – an impeller
 - As the impeller spins, liquid between the blades is impelled outward by centrifugal force
 - As liquid in the impeller moves outward, it will suck more liquid behind it through this eye

#1: If there is any danger that foreign material may be sucked into the pump, clogging or wearing of the impeller unduly, provide the intake end of the suction piping with a suitable screen

Impeller

- Bronze or stainless steel
- Closed; some single-suction have semi-open; open designs
- Inspect regularly
- As the impeller wears on a pump, the pump efficiency will decrease



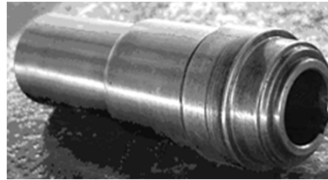
Let's Build a Centrifugal Pump

- Now we need a shaft to support and turn the impeller
 - It must maintain the impeller in precisely the right place
 - But that ruggedness does not protect the shaft from the corrosive or abrasive effects of the liquid pumped, so we must protect it with sleeves slid on from either end

#2: Never pump a liquid for which the pump was not designed

Shaft and Sleeves

- Shaft
 - Connects impeller to pump; steel or stainless steel
 - Should be repaired/replaced if grooves or scores appear on the shaft
- Shaft Sleeves
 - Protect shaft from wear from packing rings
 - Generally, they are bronze, but various other alloys, ceramics, glass or even rubber-coating are sometimes required.



Let's Build a Centrifugal Pump

- We mount the shaft on sleeve, ball or roller bearings
 - If bearings supporting the turning shaft and impeller are allowed to wear excessively and lower the turning units within a pump's closely fitted mechanism, the life and efficiency of that pump will be seriously threatened.

#3: Keep the right amount of the right lubricant in bearings at all times.

Bearings

- Anti-friction devices for supporting and guiding pump and motor shafts
- Get noisy as they wear out
- If pump bearings are over lubricated, the bearings will overheat and can be damaged or fail
 - Tiny indentations high on the shoulder of a bearing or race is called brinelling
 - When greasing a bearing on an electric motor, the relief plug should be removed and replaced after the motor has run for a few minutes. This prevents you from damaging the seals of the bearing.
- Types: ball, roller, sleeve

Let's Build a Centrifugal Pump

- To connect with the motor, we add a coupling flange
 - Our pump is driven by a separate motor, and we attach a flange to one end of the shaft through which bolts will connect with the motor flange
 - If shafts are met at an angle, every rotation throws tremendous extra load on bearings of both pump and the motor

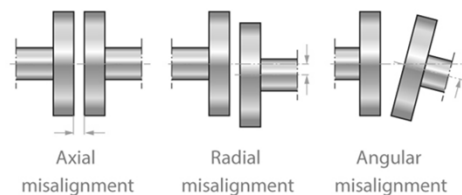
#4: See that pump and motor flanges are parallel and vertical and that they stay that way.

Couplings

- Connect pump and motor shafts
- Lubricated require greasing at 6 month intervals
- Dry has rubber or elastomeric membrane
- Calipers and thickness gauges can be used to check alignment on flexible couplings

Misalignment of Pump & Motor

- Excessive bearing loading
- Shaft bending
- Premature bearing failure
- Shaft damage
- Checking alignment should be a regular procedure in pump maintenance.
 - Foundations can settle unevenly
 - Piping can change pump position
 - Bolts can loosen
 - Misalignment is a major cause of pump and coupling wear.



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Common Pump & Motor Connections

- Close-coupled
- Frame mounted
 - Direct coupling
 - Angle drive
 - Belt or chain
 - Flexible coupling

Close Coupled Frame Mounted

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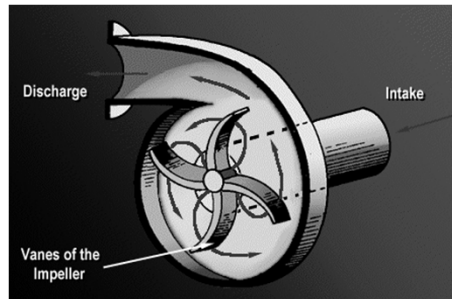
Let's Build a Centrifugal Pump

- Now we need a “straw” through which liquid can be sucked
 - The horizontal pipe slopes upward toward the pump so that air pockets won't be drawn into the pump and cause loss of suction

#5: Any down-sloping toward the pump in suction piping should be corrected

Let's Build a Centrifugal Pump

- We contain and direct the spinning liquid with a casing
 - Designed to minimize friction loss as water is thrown outward from impeller
 - Usually made of cast iron, spiral shape



#6: See that piping puts absolutely no strain on the pump casing.

Mechanical Details of Centrifugal Pumps

- Casing
 - Housing surrounding the impeller; also called the volute
 - Designed to minimize friction loss as water is thrown outward from impeller
 - Usually made of cast iron, spiral shape

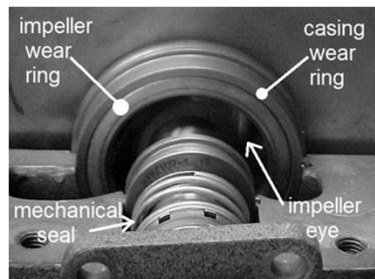
Let's Build a Centrifugal Pump

- Now our pump is almost complete, but it would leak like a sieve
 - As water is drawn into the spinning impeller, centrifugal force causes it to flow outward, building up high pressure at the outside of the pump (which will force water out) and creating low pressure at the center of the pump (which will draw water in)
- Water tends to be drawn back from pressure to suction through the space between the impeller and casing – this needs to be plugged

Let's Build a Centrifugal Pump

- So, we add wear rings to plug internal liquid leakage
 - Wear rings fill the gaps without having to move the parts of the pump closer together

#7: Never allow a pump to run dry. Water is a lubricant between the rings and impeller.



Wear Rings

- Restrict flow between impeller discharge and suction
- Leakage reduces pump efficiency
- Installed to protect the impeller and pump casing from excessive wear
- Provides a replaceable wearing surface
- Inspect regularly

#8: Examine wearing rings at regular intervals. When seriously worn, their replacement will greatly improve pump efficiency.

Let's Build a Centrifugal Pump

- To keep air from being drawn in, we use stuffing boxes
 - We have two good reasons for wanting to keep air out of our pump
 - We want to pump water, not air
 - Air leakage is apt to cause our pump to lose suction
 - Each stuffing box we use consists of a casing, rings of packing, seal cage, and a gland at the outside end
 - A mechanical seal may be used instead

Stuffing Box

#9 – Packing should be replaced periodically. Forcing in a ring or two of new packing instead of replacing worn packing is bad practice. It is apt to dislodge the seal cage.

#10 – Never tighten a gland more than necessary as excessive pressure will wear shaft sleeves unduly.

#11 – If shaft sleeves are badly scored, replace them immediately.

Packing Rings

- Asbestos or metal ring lubricated with Teflon or graphite
- Provides a seal where the shaft passes through the pump casing in order to keep air from being drawn or sucked into the pump and/or the water being pumped from coming out

Packing Rings

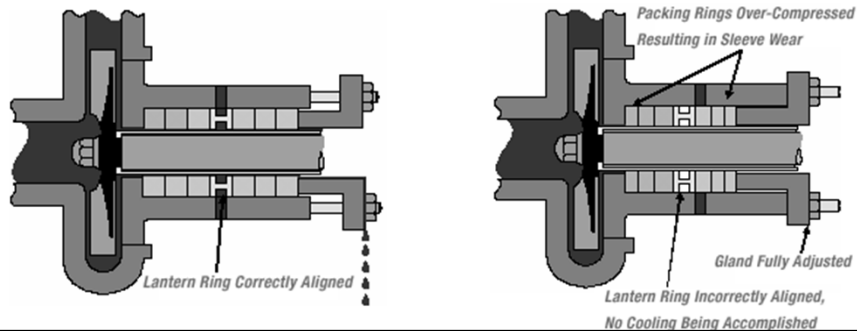
- If new packing leaks, stop the motor and repack the pump
- Pumps need new packing when the gland or follower is pulled all the way down
- The packing around the shaft should be tightened slowly, over a period of several hours to just enough to allow an occasional drop of liquid
 - Leakage acts as a lubricant
- Stagger packing joints
 - 180° if only 2 rings are in stuffing box
 - 120° for 3 rings
 - 90° if 4 rings or more are in set

Packing Rings

- If packing is not maintained properly, the following troubles can arise:
 - Loss of suction due to air being allowed to enter pump
 - Shaft or shaft sleeve damage
 - Water or wastewater contaminating bearings
 - Flooding of pump station
 - Rust corrosion and unsightliness of pump and area

Lantern Rings (aka Seal Cage)

- Perforated ring placed in stuffing box
- A spacer ring in the packing gland that forms seal around shaft, helps keep air from entering the pump and lubricates packing



Let's Build a Centrifugal Pump

- To make packing more airtight, we add water seal piping
 - In the center of each stuffing box is a “seal cage”
 - This liquid acts both to block out air intake and to lubricate the packing
 - To control liquid flow, draw up the packing gland just tight enough to allow approximately one drop every 2-3 seconds flow from the box

#12 – If the liquid being pumped contains grit, a separate source of sealing liquid should be obtained.

Mechanical Seals

- Located in stuffing box
- Prevents water from leaking along shaft; keeps air out of pump
- Should not leak
- Consists of a rotating ring and stationary element
- The operating temperature on a mechanical seal should never exceed 160°F (71°C)
- Mechanical seals are always flushed in some manner to lubricate the seal faces and minimize wear
 - The flushing water pressure in a water-lubricated wastewater pump should be 3-5 psi higher than the pump discharge pressure.



Mechanical Seals

- Required instead of packing rings for suction head greater than 60 psi
- Prevents water from leaking along shaft, keeps air out of pump
 - Should not leak any water

Packing vs. Mechanical Seals

- If a pump has packing, water should drip slowly
- If it has a mechanical seal, no leakage should occur

Packing Rings vs. Mechanical Seal

- | | |
|---|--|
| <ul style="list-style-type: none">• Advantages<ul style="list-style-type: none">– Less expensive, short term– Can accommodate some looseness | <ul style="list-style-type: none">• Disadvantages<ul style="list-style-type: none">– Increased wear on shaft or shaft sleeve– Increased labor required for adjustment and replacement |
|---|--|



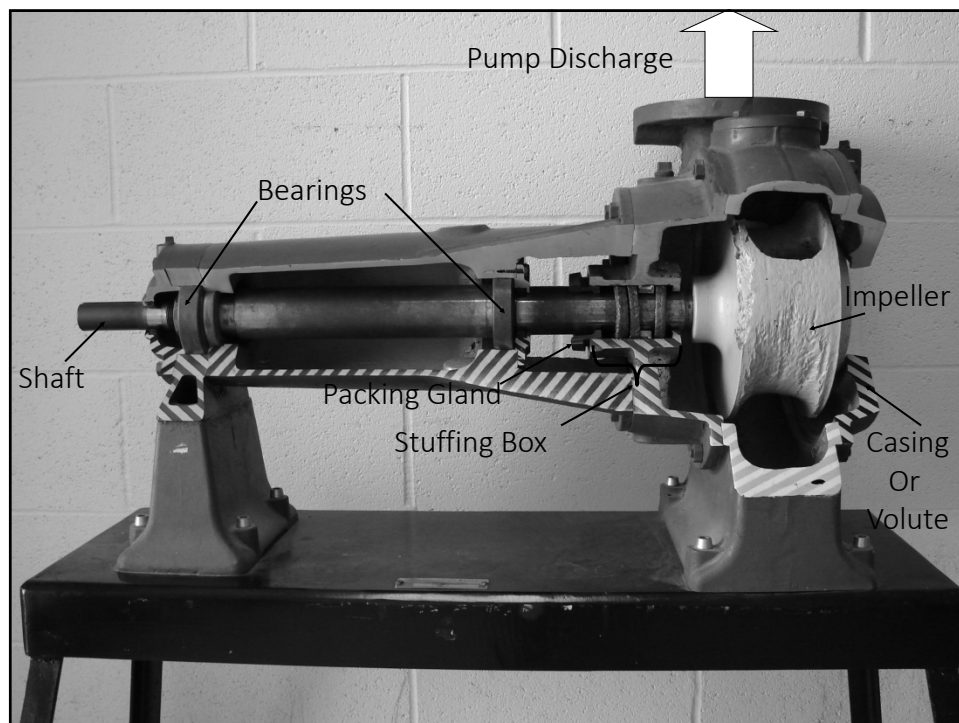
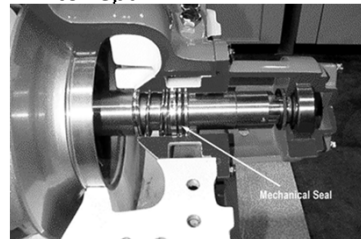
Mechanical Seal vs. Packing Rings

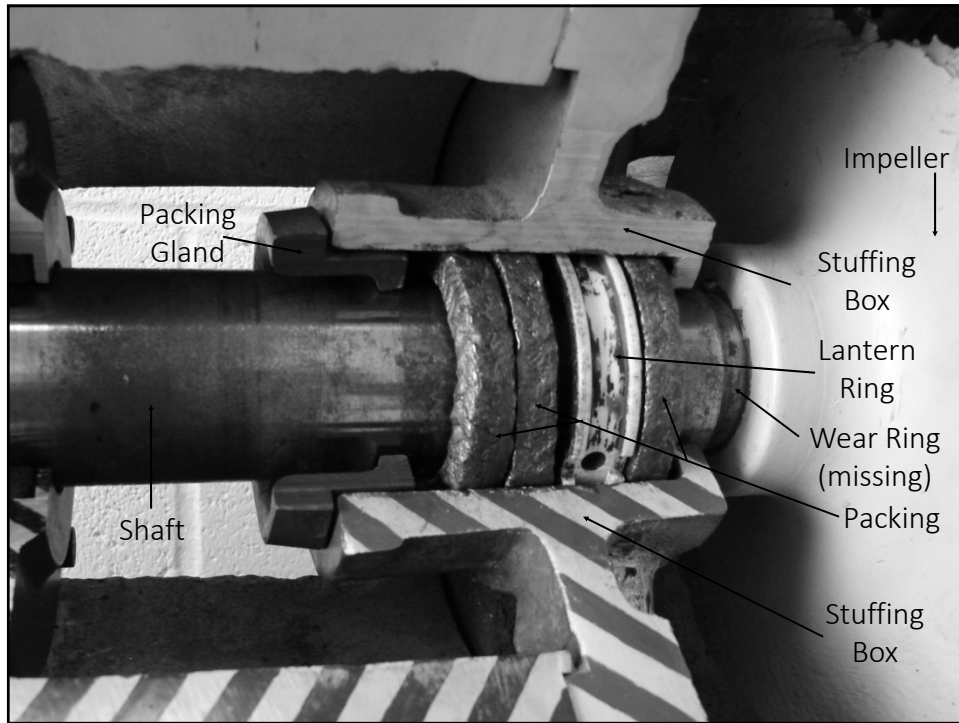
- Advantages

- Last 3-4 years, which can be a savings in labor
- Usually there is no damage to shaft sleeve
- Continual adjusting, cleaning or repacking is not required
- Possibility of flooding lift station because a pump has thrown its packing is eliminated; however mechanical seals can fail and lift stations can be flooded

- Disadvantages

- High initial cost
- Great skill and care needed to replace
- When they fail, the pump must be shut down
- Pump must be dismantled to repair





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Pump Operations



Centrifugal Pump Operation

- Pump Starting -
 - Impeller must be submerged for a pump to start
 - Should never be run empty, except momentarily, because parts lubricated by water would be damaged
 - Foot valve helps hold prime
 - Discharge valve should open slowly to control water hammer
 - In small pumps, a check valve closes immediately when pump stops to prevent flow reversal
 - In large pumps, discharge valve may close before pump stops

Centrifugal Pump Operation

- Pump shut down for extended period of time -
 - Close the valve in the suction line
 - Close the valve in the discharge line
 - Drain the pump casing

Flow Control

- Flow usually controlled by starting and stopping pumps
- Throttling flow should be avoided - wastes energy
- Variable speed drives or motor are best way to vary flow
 - Variable speed pumping equipment can be adjusted to match the inflow rate

Monitoring Operational Variables

- Pump and motor should be tested, and complete test results recorded as a baseline for the measurement of performance within the first 30 days of operation

Monitoring Operational Variables

- Suction and Discharge Heads
 - Pressure gauges
- Bearing and Motor Temperature
 - Temp indicators can shut down pump if temp gets too high
 - Check temp of pump by feel
 - Do not touch a hot motor!

Monitoring Operational Variables

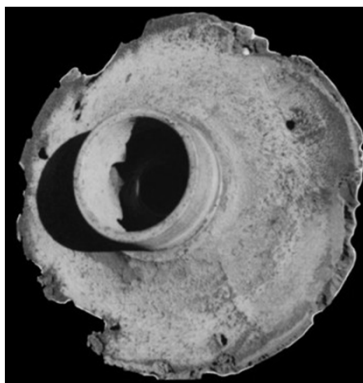
- Vibration
 - Detectors can sense malfunctions causing excess vibration
 - Operators can learn to distinguish between normal and abnormal sounds



Monitoring Operational Variables

- Likely causes of vibration
 - Bad bearings or bearing failure
 - Imbalance of rotating elements, damage to impeller
 - Misalignment from shifts in underlying foundation
 - Improper motor to pump alignment

Monitoring Operational Variables



- Speed
 - Cavitation can occur at low and high speeds
 - Creation of vapor bubbles due to partial vacuum created by incomplete filling of the pump

Monitoring Operational Variables

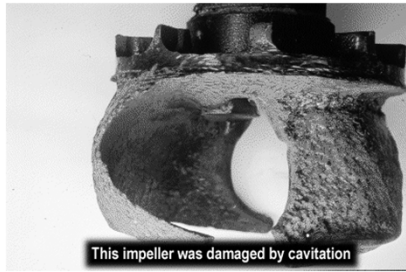
- Cavitation is a noise coming from a centrifugal pump that sounds like marbles trapped in the volute
- A condition where small bubbles of vapor form and explode against the impeller, causing a pinging sound
- Best method to prevent it from occurring is to reduce the suction lift

Inspection and Maintenance

- Inspection and maintenance prolongs life of pumps
 - Checking operating temperature of bearings
 - Checking packing glands
 - Operating two or more pumps of the same size alternatively to equalize wear
 - Check parallel and angular alignment of the coupling on the pump and motor
 - A feeler gauge, dial indicator calipers are tools that can be used to check proper alignment
- Necessary for warranty
- Keep records of all maintenance on each pump
- Keep log of operating hours

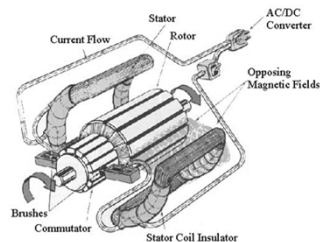
Inspection: Impellers

- Wear on impeller and volute
- Cavitation marks
- Chips, broken tips, corrosion, unusual wear
- Tightness on shaft
- Clearances
- Tears or bubbles (if rubber coated)



Pump Won't Start?

- Incorrect power supply
- No power supply
- Incorrectly connected
- Fuse out, loose or open connection
- Rotating parts of motor jammed mechanically
- Internal circuitry open



Pump Safety

- Machinery should always be turned off and locked out/tagged out before any work is performed on it
- Make sure all moving parts are free to move and all guards in place before restarting
- Machinery creating excessive noise shall be equipped with mufflers.



Pump Safety

- Lockout/Tagout
 - Standardized safety practices used to disable equipment and prevent accidental release of hazardous energy during repair or maintenance
 - Common forms of stored energy
 - Electrical energy, spring-loaded equipment, hydraulic pressure, compressed gases

Pump Safety

- Lockout/Tagout
 - Basic elements of a lockout/tagout procedure
 - Notify all affected employees that a lockout/tagout system is to be used and why
 - Shut down equipment to be serviced
 - Operate energy isolating devices to equipment is isolated
 - Lockout and tagout the device with your individual lock
 - Operate equipment normally to ensure isolation
 - Work may begin
 - Notify affected employees
 - Restore energy to equipment

Pump and Motor Facts

Pump Facts

High-service pump – discharges water under pressure to the distribution system.

Booster pump – used to increase pressure in the distribution system and to fill elevated storage tanks.

Impeller or centrifugal pump used to move water.

Likely causes of vibration in an existing pump/motor installation:

1. bad bearings
2. imbalance of rotating elements
3. misalignment from shifts in underlying foundation

Pump and motor should be tested and complete test results recorded as a baseline for the measurement of performance within the first 30 days of operations.

Calipers and thickness gauges can be used to check alignment on flexible couplings.

Packing/Seals Facts

If new packing leaks, stop the motor and repack the pump.

Pumps need new packing when the gland or follower is pulled all the way down.

The packing around the shaft should be tightened just enough to allow an occasional drop of liquid.

Joints of packing should be staggered at least 90°.

Mechanical seals consist of a rotating ring and stationary element.

The operating temperature on a mechanical seal should never exceed 160°F.

Motor Facts

Motors pull the most current on start up.

In order to prevent damage, turn the circuit off immediately if the fuse on one of the legs of a three-phase circuit blows.

An electric motor changes electrical energy into mechanical energy.

Power factors on motors can be improved by:

1. changing the motor loading
2. changing the motor type
3. using capacitors

Routing cleaning of pump motors includes:

1. checking alignment and balance
2. checking brushes
3. removing dirt and moisture
4. removal of obstructions that prevent air circulation

Cool air extends the useful life of motors.

A motor (electrical or internal combustion) used to drive a pump is called a prime mover.

The speed at which the magnetic field rotates is called the motor synchronous speed and is expressed in rpm.

If a variable speed belt drive is not to be used for 30 days or more, shift the unit to minimum speed setting.

Emory cloth should not be used on electric motor components because it is electrically conductive and may contaminate parts.

Ohmmeters used to test a fuse in a motor starter circuit.

The most likely cause of a three-phase motor not coming to speed after starting – the motor has lost power to one or more phases.

Transformer Facts

Transformers are used to convert high voltage to low voltage.

High voltage is 440 volts or higher.

Standby engines should be run weekly to ensure that it is working properly.

Relays are used to protect electric motors.

Pump Vocabulary

1. Axial-Flow Pump – a pump in which a propeller-like impeller forces water out in the direction parallel to the shaft. Also called a propeller pump.
2. Bearing – anti-friction device used to support and guide a pump and motor shafts.
3. Casing – the enclosure surrounding a pump impeller, into which the suction and discharge ports are machined.
4. Cavitation – a condition that can occur when pumps are run too fast or water is forced to change direction quickly. A partial vacuum forms near the pipe wall or impeller blade causing potentially rapid pitting of the metal.
5. Centrifugal Pumps – a pump consisting of an impeller on a rotating shaft enclosed by a casing having suction and discharge connections. The spinning impeller throws water outward at high velocity, and the casing shape converts this velocity to pressure.
6. Closed-Coupled Pump – a pump assembly where the impeller is mounted on the shaft of the motor that drives the pump.
7. Diffuser Vanes – vanes installed within a pump casing on diffuser centrifugal pumps to change velocity head to pressure head.
8. Double-Suction Pump – a centrifugal pump in which the water enters from both sides of the impeller. Also called a split-case pump.
9. Foot Valve – a check valve placed in the bottom of the suction pipe of a pump, which opens to allow water to enter the suction pipe but closes to prevent water from passing out of it at the bottom end. Keeps prime.
10. Frame-Mounted Pump – a centrifugal pump in which the pump shaft is connected to the motor shaft with a coupling.
11. Impeller – the rotating set of vanes that forces water through the pump.
12. Jet Pump – a device that pumps fluid by converting the energy of a high-pressure fluid into that of a high-velocity fluid.
13. Lantern Ring – a perforated ring placed around the pump shaft in the stuffing box. Water from the pump discharge is piped to this ring. The water forms a liquid seal around the shaft and lubricates the packing.
14. Mechanical Seal – a seal placed on the pump shaft to prevent water from leaking from the pump along the shaft; the seal also prevents air from entering the pump.
15. Mixed-Flow Pump – a pump that imparts both radial and axial flow to the water.
16. Packing – rings of graphite-impregnated cotton, flax, or synthetic materials, used to control leakage along a valve stem or a pump shaft.
17. Packing Gland – a follower ring that compressed the packing in the stuffing box.
18. Positive Displacement Pump – a pump that delivers a precise volume of liquid for each stroke of the piston or rotation of the shaft.
19. Prime Mover – a source of power, such as an internal combustion engine or an electric motor, designed to supply force and motion to drive machinery, such as a pump.

20. Radial-Flow Pump – a pump that moves water by centrifugal force, spinning the water radially outward from the center of the impeller.
21. Reciprocating Pump – a type of positive-displacement pump consisting of a closed cylinder containing a piston or plunger to draw liquid into the cylinder through an inlet valve and forces it out through an outlet valve.
22. Rotary Pump – a type of positive-displacement pump consisting of elements resembling gears that rotate in a close-fitting pump case. The rotation of these elements alternately draws in and discharges the water being pumped.
23. Single-Suction Pump – a centrifugal pump in which the water enters from only one side of the impeller. Also called an end-suction pump.
24. Stuffing Box – a portion of the pump casing through which the shaft extends and in which packing or a mechanical seal is placed to prevent leakage.
25. Submersible Pump – a vertical-turbine pump with the motor placed below the impellers. The motor is designed to be submersed in water.
26. Suction Lift – the condition existing when the source of water supply is below the centerline of the pump.
27. Velocity Pump – the general class of pumps that use a rapidly turning impeller to impart kinetic energy or velocity to fluids. The pump casing then converts this velocity head, in part, to pressure head. Also known as kinetic pumps.
28. Vertical Turbine Pump – a centrifugal pump, commonly of the multistage, diffuser type, in which the pump shaft is mounted vertically.
29. Volute – the expanding section of pump casing (in a volute centrifugal pump), which converts velocity head to pressure head..
30. Water Hammer – the potentially damaging slam that occurs in a pipe when a sudden change in water velocity (usually as a result of too-rapidly starting a pump or operating a valve) creates a great increase in water pressure.
31. Wear Rings – rings made of brass or bronze placed on the impeller and/or casing of a centrifugal pump to control the amount of water that is allowed to leak from the discharge to the suction side of the pump.

Pump and Motor Review Questions

1. Leakage of water around the packing on a centrifugal pump is important because it acts as a (n):
 - a. Adhesive
 - b. Lubricant
 - c. Absorbent
 - d. Backflow preventer
2. What is the purpose of wear rings in a pump?
 - a. Hold the shaft in place
 - b. Hold the impeller in place
 - c. Control amount of water leaking from discharge to suction side
 - d. Prevent oil from getting into the casing of the pump
3. Which of the following does a lantern ring accomplish?
 - a. Lubricates the packing
 - b. Helps keep air from entering the pump
 - c. Both (a.) and (b.)
4. Closed, open and semi-open are types of what pump part?
 - a. Impeller
 - b. Shaft sleeve
 - c. Casing
 - d. Coupling
5. When tightening the packing on a centrifugal pump, which of the following applies?
 - a. Tighten hand tight, never use a wrench
 - b. Tighten to 20 foot pounds of pressure
 - c. Tighten slowly, over a period of several hours
 - d. Tighten until no leakage can be seen from the shaft
6. Excessive vibrations in a pump can be caused by:
 - a. Bearing failure
 - b. Damage to the impeller
 - c. Misalignment of the pump shaft and motor
 - d. All of the above
7. What component can be installed on a pump to hold the prime?
 - a. Toe valve
 - b. Foot valve
 - c. Prime valve
 - d. Casing valve

8. The operating temperature of a mechanical seal should not exceed:
 - a. 60°C
 - b. 150°F
 - c. 160°F
 - d. 71°C
 - e. c and d
9. What is the term for the condition where small bubbles of vapor form and explode against the impeller, causing a pinging sound?
 - a. Corrosion
 - b. Cavitation
 - c. Aeration
 - d. Combustion
10. The first thing that should be done before any work is begun on a pump or electrical motor is:
 - a. Notify the state
 - b. Put on safety goggles
 - c. Lock out the power source and tag it
 - d. Have a competent person to supervise the work
11. Under what operating condition do electric motors pull the most current?
 - a. At start up
 - b. At full operating speed
 - c. At shut down
 - d. When locked out
12. Positive displacement pumps are rarely used for water distribution because:
 - a. They require too much maintenance
 - b. They are no longer manufactured
 - c. They require constant observation
 - d. Centrifugal pumps are much more efficient
13. Another name for double-suction pump is
 - a. Double-jet pump
 - b. Reciprocating pump
 - c. Horizontal split-case pump
 - d. Double-displacement pump
14. As the impeller on a pump becomes worn, the pump efficiency will:
 - a. Decrease
 - b. Increase
 - c. Stay the same
15. How do the two basic parts of a velocity pump operate?

16. What are two designs used to change high velocity to high pressure in a pump?
17. In what type of pump are centrifugal force and the lifting action of the impeller vanes combined to develop the total dynamic head?
18. Identify one unique safety advantage that velocity pumps have over positive-displacement pumps.
19. What is the multistage centrifugal pump? What effects does the design have on discharge pressure and flow volume?
20. What are two types of vertical turbine pump, as distinguished by pump and motor arrangement, which are commonly used to pump ground water from wells?
21. What type of vertical turbine pump is commonly used as an inline booster pump?
22. Describe the two main parts of a jet pump.
23. What is the most common used of positive-displacement pumps in water plants today?
24. What is the purpose of the foot valve on a centrifugal pump?

25. How is the casing of a double-suction pump disassembled?
26. What is the function of wear rings in centrifugal pumps of the closed-impeller design? What is the function of the lantern rings?
27. Describe the two common types of seals used to control leakage between the pump shaft and the casing.
28. What feature distinguishes a close-coupled pump and motor?
29. What is the value of listening to a pump or laying a hand on the unit as it operates?
30. Define the term “racking” as applied to pump and motor control.
31. When do most electric motors take the most current?
32. What are three major ways of reducing power costs where electric motors are used?
33. What effect could over lubrication of motor bearings have?

34. Why should emery cloth not be used around electrical machines?
35. What are the most likely causes of vibration in an existing pump installation?
36. What can happen when a fuse blows on a single leg of a three-phase circuit?
37. Name at least three common fuels for internal-combustion engines.
38. List the type of information that should be recorded on a basic data card for pumping equipment.
39. What is the first rule of safety when repairing electrical devices?

Answers:

- | | | |
|------|-------|-------|
| 1. B | 6. D | 11. A |
| 2. C | 7. B | 12. D |
| 3. C | 8. E | 13. C |
| 4. A | 9. B | 14. A |
| 5. C | 10. C | |
15. A spinning impeller accelerates water to a high velocity within a casing, which changes the high-velocity, low-pressure water to a low-velocity, high-pressure discharge.
 16. Volute casing and diffuser vanes.
 17. Mixed-flow pump (the design used for most vertical turbine pumps)
 18. If a valve is closed in the discharge line, the pump impeller can continue to rotate for a time without pumping water or damaging the pump.
 19. A multistage centrifugal pump is made up of a series of impellers and casings (housings) arranged in layers, or stages. This increases the pressure at the discharge outlet, but does not increase flow volume.
 20. Shaft-type and submersible-type vertical turbines.
 21. A close-coupled vertical turbine with an integral sump or pot.
 22. The jet pump consists of a centrifugal pump at the ground surface and an ejector nozzle below the water level.
 23. Positive-displacement pumps are generally used in water plants to feed chemical into the water supply.
 24. The foot valve prevents water from draining when the pump is stopped, so the pump will be primed when restarted.
 25. The bolts holding the two halves of the casing together are removed and the top half is lifted off.
 26. Wear rings prevent excessive circulation of water between the impeller discharge and suction area. Lantern rings allow sealing water to be fed into the stuffing box.
 27. (1) Packing rings are made of graphite-impregnated cotton, flax, or synthetic materials. They are inserted in the stuffing box and held snugly against the shaft by an adjustable packing gland. (2) Mechanical seals consist of two machined and polished surfaces. One is attached to the shaft, the other to the casing. Spring pressure maintains contact between the two surfaces.
 28. The pump impeller is mounted directly on the shaft of the motor.
 29. An experienced operator can often detect unusual vibration by simply listening or touching. Vibration, especially changes in vibration level, are viewed as symptoms or indicators of other underlying problems in foundation, alignment and/or pump wear.
 30. Racking refers to erratic operation that may result from pressure surges when the pump starts; it is often a problem when the pressure sensor for the pump control is located too close to the pump station.
 31. During start-up.
 32. (1) Increase system efficiency; (2) spread the pumping load more evenly throughout the day; (3) reduce power-factor charges
 33. The bearings may run hot, and excess grease or oil could run out and reach the motor windings, causing the insulation to deteriorate.
 34. The abrasive material on emery cloth is electrically conductive and could contaminate electrical components.
 35. Imbalance of the rotating elements, bad bearings and misalignment
 36. A condition called single-phasing can occur, causing the motor windings to overheat and eventually fail.

37. gasoline, propane, methane, natural gas and diesel oil (diesel fuel)
38. make, model, capacity, type, date and location installed, and other information for both the driver (motor) and the driven unit (pump)
39. Make sure the power to the device is disconnected. This is critical since rubber gloves, insulated tools and other protective gear are not guarantees against electrical shock.

Section 7

System Management

CSUS: Water Treatment Plant Operation, Vol. 2



Department of
**Environment &
Conservation**

Management

Objectives

- Managing Utilities
- Planning
- Organizing
- Staffing
- Communication
- Public Relations
- Planning for Financial Stability
- Operation and Maintenance
- Emergency Response
- Safety Program
- Recordkeeping
- Water & Energy Conservation

Managing Utilities

- Management of public utility is a complex and challenging job
 - Community demands
 - Increasingly strict regulations
 - Personnel
 - Resources
 - Equipment
 - Future preparations
- Basic functions of utility manager
 - Planning
 - Organizing
 - Staffing
 - Directing
 - Controlling

Managing Utilities

- Planning
 - Management of utilities to build resources and financial capability to provide for future needs
- Organizing
 - Deciding who does what work and delegating authority to the appropriate person
- Staffing
 - Recruiting of new operators and other staff
- Directing
 - Includes guiding, teaching, motivating, and supervising
- Controlling
 - Taking steps needed to ensure that essential activities are performed so objectives can be achieved as planned

Feasibility Analysis Process

- A series of prescribed steps that will lead you to the most cost-effective solution

Planning



Planning

- One of the most important and most difficult functions of utility manager
 - Building resources and financial capability to provide for future needs
 - Recognizing and plan for declines in population
 - Preventative maintenance programs should be established and maintained
 - Emergency Response Plan must be created for utility

Organizing



Organizing

- Utility should have an organizational plan with written policies
 - Shows who reports to whom and identifies lines of authority
 - Includes job description for each position on chart
 - Each employee can only serve one supervisor (unity of command)
 - Each supervisor should only have 6-7 employees

Organizing

- Authority
 - Power and resources to do a specific job
- Responsibility
 - Answering to those above in chain of command to explain how and why you have used your authority
- Delegation
 - Act in which power is given to another person to accomplish a specific job
- Accountability
 - When a manager gives power/responsibility to an employee, the employee ensures the manager is informed of the results or events

Staffing



Staffing

- Manager responsible for hiring new employees, training employees, and evaluating job performance
- Any personnel action taken must be job-related
- Documentation of personnel actions is essential

Workforce Analysis

- Review of the agency's work requirements and staffing when completing the annual budget
 - Prepare a detailed list of all the tasks to be performed to operate and maintain the utility
 - Estimate the number of staff hours per year required to perform each task (include supervision and training)
 - Prepare a list of the utility's current employees
 - Assign tasks to each employee based on the person's skills and abilities
 - Try to minimize the number of different work activities to each person while remembering to provide room for advancement

Qualifications Profile

- Selection method and examination process must be limited to the applicant's knowledge, skills, and abilities to perform relevant job-related activities
- Job description can be used to create qualification profile
- Typical Qualification Profile might include
 - General requirements
 - General education development
 - Specific vocational preparation
 - Interests
 - Temperament
 - Physical demands
 - Working conditions

Applications and the Selection Process

- Advertise the position
- Paper screening
 - Review each application and eliminate those that are not qualified
- Interview applicants
 - Create list of job-related questions that will be asked of every candidate
 - Only ask about applicant's job skills, abilities, and experience relating directly to the job for which the person is applying
 - Explain details of job, working conditions, wages, benefits, and potential for advancement
 - Allow applicant to ask questions about the job
- Select most qualified candidate

Applications and the Selection Process

- Responsibilities regarding protected groups such as minorities, women, disabled persons, persons of 40 years of age, and union members begins during the hiring process
- OUCH
 - Objectivity
 - Uniform treatment of employees
 - Consistent with utility policies
 - Have job relatedness

New Employee Orientation

- On first day, provide all information available in written and verbal form on the policies and practices of the utility
- Introduce new employees to coworkers
- Provide required safety training

Employment Policies and Procedures

- Probationary Period
 - Time during which both the employer and employee can assess the fit between the job and the person
- Compensation
 - Includes satisfaction, recognition, security, appropriate pay, and benefits
- Training and Certification
 - All water treatment plant operators (OIDC) must be certified in US
- Performance Evaluation
 - Complete annually to provide employees with positive feedback as well as let them know what is expected of them
- Dealing with Disciplinary Problems
 - Begin with verbal warning; proceed to written warnings; suspension or dismissal may be required

Labor Laws Governing Employer/Employee Relations

- Equal Employment Opportunity Act (EEOA)
 - Employers do not discriminate based on race, religion, national origin, color, citizenship, marital status, gender, age, Vietnam-era or disabled veteran status, or the presence of a physical, mental or sensory disability
- Family Medical Leave Act (FMLA)
 - Requires employers to permit eligible employees to take up to 12 weeks of time off in a 12-month period
 - Employee's health, care for a new child, care for employee's spouse, child, or parent
- Americans with Disabilities Act (ADA)
 - Employers must make reasonable accommodations to enable a disabled person to function successfully in a work environment

Communication



Communication

- Communication is a two-part process
 - Information must be given
 - Information must be understood
- Oral Communication
 - Informal such as talking to employees
 - Formal such as a technical presentation
- Written Communication
 - Keep audience in mind and write it to be applicable to them
 - Annual Report should be a review of what and how the utility operated over the last year as well as goals for next year

Public Relations



Department of
**Environment &
Conservation**

Public Relations

- “A strategic communication process that builds mutually beneficial relationships between organizations and their publics”
- Establish Objectives
- Utility Operations
- Mass Media
- Being Interviewed (utility should have designated spokesperson)
- Public Speaking
- Telephone Contacts
- Consumer Inquiries
- Plant Tours

Planning for Financial Stability



Financial Stability

- Financial management of a utility should include
 - providing financial stability for the utility
 - careful budgeting
 - providing capital improvement funds for future utility expansion
- Measuring Stability
 - Operating Ratio
 - Measure of the total revenues divided by the total operating expenses
 - Typically, above 1
 - Coverage Ratio
 - Measure of the ability of a utility to pay the principal and interest on loans and bonds (debt service)
 - Greater than 1.25

Financial Stability

- Budgeting
 - Manager must understand
 - How money has been spent
 - Needs of the utility
 - How needs should be prioritized
 - Uncontrollable costs increase
 - Utilize annual report to aid in development of budget so long-term planning will be included

Financial Stability

- Equipment Repair/Replacement Fund
 - Purpose is to generate additional revenue to pay for the repair and replacement of capital equipment as it wears out
 - Make asset inventory of all capital equipment including
 - Replacement costs
 - Expected life span
- Water Rates
 - Development of a rate schedule involves
 - Determination of total revenue requirements
 - Determination of all the cost components of system operations
 - Distribution of various components costs to various customer classes
 - Design of water rates that will recover from each class of customers the cost to serve them

Financial Stability

- Capital Improvement Program (CIP)
 - Detailed plan that identifies requirements and a budget for the repair, replacement, rehabilitation, and expansion of a facility infrastructure over a multiyear period
 - Each year, use annual reports to develop a list of expected capital improvements that will need to be made over the next year, 2 years, 5 years, and 10 years
 - When considering different plans for improvement, calculate the present worth
 - Value of long-term project expressed in today's dollars
 - Apply standard inflation, depreciation, and other economic factors
 - Financing available through general obligation bonds (ad valorem), revenue bonds, or loan funding programs and grants
 - State Revolving Fund (SRF)

Operation and Maintenance



Operation & Maintenance

- Effective O & M programs are based on
 - Knowing what components make up the system
 - Where they are located
 - Condition of the components
- Using Geographic Information Systems (GIS)
 - Computer program that combines mapping with detailed information about the physical structures
 - An inventory of system components and their appurtenances
 - Identified components entered into program to as “attributes”

Types of Maintenance

- Corrective Maintenance (reactive)
 - Maintenance only performed when the equipment or system fails
 - Includes emergency maintenance
 - Normal emergencies – reduced by effective maintenance program
 - Extraordinary emergencies – unpredictable occurrences
- Preventive Maintenance (proactive)
 - Programmed systematic approach to maintenance activities
 - Will always result in improved system performance
- Predictive Maintenance (proactive)
 - Establishing a baseline performance data
 - Monitoring performance criteria
 - Observing changes in performance so that failure can be predicted, and maintenance can be performed before failure occurs

Operation & Maintenance

- Benefits of Managing Maintenance
 - Goal is to minimize investments while delivering a high level of service
- SCADA Systems
 - Supervisory Control And Data Acquisition
 - Nerve center of a water utility
 - Collects, stores, and analyzes information about all aspects of operation and maintenance
 - Transmits alarm signals
 - Allows fingertip control of alarms, equipment, and processes

Cross Connection Control Program

- Backflow of contaminated water through cross-connections has caused more waterborne disease outbreaks in the US than any other reported factor
- Backflow results from
 - Back pressure
 - Backsiphonage
- Measures to prevent backflow
 - Severe any direct connection
 - Require air gap separation
 - Install check valve

Cross Connection Control Program

- Program Responsibilities
 - Water Suppliers
 - Responsible for preventing contamination by backflow
 - Water Users
 - Responsible for keeping contaminants out of the potable water system on their premises
 - Health Agency
 - Responsible for issuing and enforcing laws, rules, regulations, and policies needed to control cross-connections
 - Plumbing Officials
 - Responsible for enforcement of building regulations relating to prevention of cross connections

Water Supplier Program

- Enactment of ordinance providing enforcement authority
- Training of personnel on causes of and hazards from cross connections and procedures to follow to prevent backflows
- List and inspect/reinspect all facilities where cross-connections are a concern
- Obtain and maintain a list of approved backflow prevention devices and a list of certified testers, if applicable
- Acceptable installation of the proper type of device
- Maintenance of records for each backflow prevention device installed, including inspection and testing records (5 years)
- Notification of customers when a backflow prevention device has to be tested (annually, after installation, after repair)
- Maintenance of adequate pressures throughout the distribution system at all times to minimize hazards from potential cross connections

Emergency Response



Federal Requirements

- Public Health Security and Bioterrorism Preparedness and Response Act of 2002
 - Conduct a vulnerability assessment (VA)
 - Certify and submit a copy of VA to EPA
 - Prepare/revise Emergency Response Plan (ERP) to incorporate VA
 - Certify ERP complete within 6 months of updating VA

Assessment and Planning

- Elements most subject to disruption during a disaster
 - Absence of trained personnel to make critical decisions and carry out orders
 - Loss of power to facilities
 - Inadequate amount of supplies and materials
 - Inadequate communication equipment

Vulnerability Assessment

- Vulnerability Assessment (VA)
 - Review of pipes & constructed conveyances
 - Physical barriers
 - Water collection
 - Pretreatment
 - Treatment
 - Storage and distribution facilities
 - Electronic or computer systems
 - Use, storage, handling of various chemicals
 - Operation and maintenance of the system

Vulnerability Assessment

- Steps to take when assessing the vulnerability of a system
 - Identify and describe the system components
 - Assign assumed disaster characteristics
 - Estimate disaster effects on system components
 - Estimate customer demand for service following disaster
 - Identify key system components that would be primarily responsible for system failure
- Once the Vulnerability Assessment is complete, an emergency plan can be drafted

Emergency Response Plan (ERP)

- Plans, procedures, and identification of equipment that can be used in the event of an attack on the PWS
- Actions, procedures, and identification of equipment which can lessen the impact of attacks
- Developing an ERP
 - Make a vulnerability assessment
 - Inventory organizational personnel
 - Provide for a recovery operation (plan)
 - Provide training programs operators implementing plan
 - Coordinate with local/regional agencies
 - Establish a communications procedure
 - Provide protection for personnel, equipment, records, and maps

Security

- Must have written plans
 - Emergency action plan
 - Fire prevention plan
- Actions to take to reduce possibility of attack
 - Ensure that all visitors sign in and out of the facility
 - Keep the number of visitors to a minimum
 - Discourage public parking near critical buildings
 - Be cautious with suspicious packages that arrive
 - Be aware of hazardous chemicals used and how to defend against spills
 - Keep emergency numbers posted near telephones and radios
 - Patrol facilities frequently
 - Require all chemical deliveries to provide ID and copies of manifest
 - Maintain, inspect, and use PPE

Security

- To guard against unplanned physical intrusion
 - Lock all doors and set alarms at office, booster pump stations, treatment plants, and vaults
 - Limit access to facilities and control access to booster pump stations, chemical and fuel storage areas
 - Post guards at treatment plants and post “Employees Only” signs in restricted areas
 - Increase lighting in parking lots, treatment bays, and other areas with limited staffing
 - Control access to computer networks and control systems; change passwords frequently
 - Do not leave keys in equipment or vehicles at any time
 - Use video surveillance cameras

Security

- Make security a priority by
 - Conducting background checks on employees at hiring and periodically
 - Develop written security plan and train employees frequently
 - Ensure all employees are aware of established procedures for communicating with emergency response personnel
 - Ensure employees are fully aware of the importance of vigilance
 - Make note of unaccompanied strangers on site and immediately notify security or local law enforcement
 - Vary the timing of operational procedures so that the pattern changes
 - Change pass codes and get all keys and access cards from dismissed employees
 - Provide customer service staff with training of how to handle a threat if called in

Evaluating & Responding to Threats

- Goals of threat response and management are to
 - Decide if a received threat is possible
 - Determine if the possible threat is credible and protect public health
 - Confirm the threat by sending water samples collected during site characterization to a lab for analysis and identification of unknown or suspected contaminants
 - Remediate the affected water system to remove or inactivate the contaminant
 - Recovery of the system

Managing Contamination Threats

- *Cryptosporidium* in Water Systems
 - Most serious threat occurs during periods of heavy rains or snow melts wash wastes into the source water
 - Conventional water treatment plants can provide effective treatment
 - Run frequent jar tests to ensure optimal coagulation dosage
 - Turbidity and particle counting measurements are used as a means for determining the treatment process' effectiveness

Safety Program



Safety Program

- Effectiveness of any safety program depends on the supervisors
 - Responsible for the implementation of any safety program
- Regulatory Agencies
 - Occupational Safety and Health Act of 1970
 - Intent is to create a place of employment that is free from recognized hazards that could cause serious physical harm or death to an employee
 - Civil and criminal penalties are allowed
 - Assessed against the supervisor responsible for the injured employee
 - Workers' Right to Refuse Dangerous Work
 - Workers' Right to Know

Safety Program


- Managers
 - Responsible for the safety of the agency's personnel and the public exposed to the water utility's operations
 - Must provide new and ongoing employee safety training
 - Must develop and administer an effective safety program
 - Safety training and promotion
 - Accident investigation and reporting
 - Safety policy statement (provide copy to every employee)
 - Define goals and objectives of program
 - Identify personnel responsible
 - Describe disciplinary action taken if needed

Safety Program










- Operators
 - Must accept responsibility for an active role in the safety program
 - Be aware of the utility's safety policy
 - Conforming to established regulations
 - Inform supervisor of any unsafe condition, environment, equipment, or other concerns
- First Aid
 - Emergency treatment for injury or sudden illness, before regular medical treatment is available
 - Well-equipped first-aid kit should be inspected regularly and prominently displayed
 - Each utility should develop and SOP for first-aid treatment of injured personnel

Hazard Communication Standard

- Basic elements of a HCS program
 - Identify hazardous materials and create inventory
 - Obtain chemical information and define hazardous conditions
 - Refer to Safety Data Sheet (SDS)
 - Properly label hazards
 - Chemical identification
 - Signal word
 - Pictogram
 - Hazard statement
 - Precautionary statement
 - Train operators

SAMPLE LABEL			
CODE _____ Product Name _____	}	Product Identifier	Hazard Pictograms  Signal Word Danger
Company Name _____ Street Address _____ City _____ State _____ Postal Code _____ Country _____ Emergency Phone Number _____	}	Supplier Identification	
<p>Keep container tightly closed. Store in a cool, well-ventilated place that is locked. Keep away from heat/sparks/open flame. No smoking. Only use non-sparking tools. Use explosion-proof electrical equipment. Take precautionary measures against static discharge. Ground and bond container and receiving equipment. Do not breathe vapors. Wear protective gloves. Do not eat, drink or smoke when using this product. Wash hands thoroughly after handling. Dispose of in accordance with local, regional, national, international regulations as specified.</p> <p>In Case of Fire: use dry chemical (BC) or Carbon Dioxide (CO₂) fire extinguisher to extinguish.</p> <p>First Aid If exposed call Poison Center. If on skin (or hair): Take off immediately any contaminated clothing. Rinse skin with water.</p>			<p>Highly flammable liquid and vapor. May cause liver and kidney damage.</p>
Precautionary Statements			Hazard Statements
Supplemental Information Directions for Use _____ _____ _____			
Fill weight: _____ Lot Number: _____ Gross weight: _____ Fill Date: _____ Expiration Date: _____			

OSHA 3492-OTR 2016

Health Hazard  <ul style="list-style-type: none"> • Carcinogen • Mutagenicity • Reproductive Toxicity • Respiratory Sensitizer • Target Organ Toxicity • Aspiration Toxicity 	Flame  <ul style="list-style-type: none"> • Flammables • Pyrophorics • Self-Heating • Emits Flammable Gas • Self-Reactives • Organic Peroxides 	Exclamation Mark  <ul style="list-style-type: none"> • Irritant (skin and eye) • Skin Sensitizer • Acute Toxicity (harmful) • Narcotic Effects • Respiratory Tract Irritant • Hazardous to Ozone Layer (Non-Mandatory)
Gas Cylinder  <ul style="list-style-type: none"> • Gases Under Pressure 	Corrosion  <ul style="list-style-type: none"> • Skin Corrosion/ Burns • Eye Damage • Corrosive to Metals 	Exploding Bomb  <ul style="list-style-type: none"> • Explosives • Self-Reactives • Organic Peroxides
Flame Over Circle  <ul style="list-style-type: none"> • Oxidizers 	Environment (Non-Mandatory)  <ul style="list-style-type: none"> • Aquatic Toxicity 	Skull and Crossbones  <ul style="list-style-type: none"> • Acute Toxicity (fatal or toxic)

Hazard Communication Standard

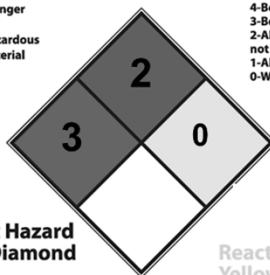
- National Fire Protection Association (NFPA)
 - May be used in place of HCS

Health Hazard Blue Diamond

4-Deadly
3-Extreme Danger
2-Hazardous
1-Slightly Hazardous
0-Normal Material

Fire Hazard Red Diamond

Flash Points
4-Below 73°F
3-Below 100°F
2-Above 100°F
not exceeding 200°F
1-Above 200°F
0-Will not burn



Specific Hazard White Diamond

ACID - Acid
ALK - Alkali
COR - Corrosive
OXY - Oxidizer
☢ - Radioactive
☒ - Use No Water

Reactivity Yellow Diamond

4-May Detonate
3-Shock & Heat may detonate
2-Violent Chemical change
1-Unstable if heated
0-Stable

Hazard Communication Standard

- Hazardous Materials Identification System (HMIS)

CHEMICAL NAME		PROTECTIVE EQUIPMENT GUIDE	
HEALTH	A	G	
FLAMMABILITY	B	H	
PHYSICAL HAZARD	C	I	
PROTECTIVE EQUIPMENT	D	J	
	E	K	
	F	X Ask your supervisor for special handling instructions.	

Reporting

- All injuries should be reported as to establish a record
- Responsibility of injured person, supervisor, and manager
- Accident report forms may be simple but must meet minimum requirements required by law
 - Name and ID of injured employee
 - Time of accident
 - Nature of injury
 - Cause of accident
 - First aid administered
 - Additional remarks
- Review by foreman, supervisor, safety officer and management followed recommendations is required

Training

- Three components
 - Safety education of all employees
 - Reinforced education in safety
 - Safety education in the use of tools and equipment
- Train all new operators before starting work
 - On-the-job training only works for the experienced operator
- Safety education must be continual
 - Tailgate safety meetings – brief safety meeting held periodically or as-needed (aka toolbox safety meeting)
 - 10-20 minutes
- A good safety record will be achieved only with good work habits and safe equipment
- Each operator must think, act and promote safety

Measuring

- Safety program must include ability to identify, measure and analyze the effects of the program
- Effectiveness of safety program can also be determined by reviewing injury statistics and calculating injury rates per year
 - Injury frequency rate
 - Measure of total injuries
 - Injury severity rate
 - Measure of lost work days

Human Factors

- Human factor engineering is the specialized study of technology relating to the design of operator-machine interfaces
- Responsibility for accidents due to human factors belongs to management
- Take every step possible during design to ensure a safe work environment is provided
- Operator is appropriate person to evaluate the means of reducing the human factor's contribution to causing accidents

Recordkeeping



Recordkeeping

- Essential records include
 - Source of supply
 - Operation
 - Laboratory
 - Maintenance
 - Chemical inventory & usage
 - Purchases
 - Chlorination station
 - Main disinfection
 - Cross-connection control
 - Personnel
 - Accidents
 - Customer complaints

Maintenance

- Procurement
 - Ordering repair parts and supplies
- Inventory
 - Consists of the supplies the treatment plant needs to keep on hand to operate the facility
- Equipment
 - Equipment control cards and work orders can be used to
 - Record important equipment data
 - Record maintenance and repair work performed
 - Anticipate preventive maintenance needs
 - Schedule future maintenance

Retaining Utility Records

- Bacteriological results 5 years
- Customer complaint file 5 years
- Cross connection control 5 years
- Storage tank inspection 5 years
- Turbidity Analysis 5 years
- Chemical analysis 10 years
- Sanitary Survey 10 years
- Lead and Copper 12 years
- Safety Data Sheet (SDS) 30 years

0400-45-1 Public Water Systems

Water & Energy Conservation



Conservation Programs

- Best Management Practices (BMP)
 - A policy, program, practice, rule, regulation, or ordinance or the use of devices equipment, or facilities that meet either of the following criteria:
 - An (generally) established practice among water suppliers that results in a more efficient use or conservation of water
 - A practice for which sufficient data are available from existing water conservation projects to indicate that significant conservation or conservation-related benefits can be achieved
 - That the practice is technically and economically reasonable and not environmentally or socially unacceptable
 - That the practice is not otherwise unreasonable for most water suppliers to carry out

Best Management Practices

- Residential Water Surveys
 - Indoor and outdoor audits of residential water use and distribution of water-saving devices
- Residential Plumbing Retrofits
 - Distribution or installation of water-saving devices in residences built before 1992
- System Water Audits, Leak Detection, and Repair
 - Annually calculate unaccounted-for water and performing distribution system water audits
- Metering with Commodity Rates
 - Requires metering of all new connections and retrofitting of existing connections to ensure metering of all consumptions and billing on the basis of the volume of water consumed

Best Management Practices

- Landscape Conservation Programs
 - Provides nonresidential customers with incentives to improve their landscape water-use efficiency
- Public Information Programs
 - Provide information to promote water conservation and water conservation-related benefits
- Commercial-, Industrial-, and Institutional-Sector Programs (CII)
 - Increases water-uses efficiency in the CII sectors
- Wholesale Agency Assistance Programs
 - Wholesaler provides support for water conservation programs of retail water suppliers

Best Management Practices



- Conservation Pricing
 - Includes uniform or increasing block rate structure, volume-related sewer charges, and service cost recovery
- Conservation Coordinator
 - Designation of a staff coordinator responsible for
 - Coordination/oversight of conservation programs and BMP implementation
- Water Waste Prohibition
 - Enacting and enforcing of measures prohibiting wasteful use of water
- Residential ULFT Replacement Programs
 - Promotes replacement of high-water-using toilets to ultra-low-flush toilets (ULFTs)

Best Management Practices

- Other potential BMPs
 - Gray water use
 - Efficiency standards for water-using appliances and irrigation devices
 - Retrofit of existing car washes
 - Distribution system pressure regulation
 - Swimming pool and spa conservation
 - Point-of-use water heaters, recirculating hot water systems, and hot water pipe insulation
 - Efficiency standards for new industrial and commercial processes
 - Rebates and utility financial incentive programs for high-efficiency clothes washers

Section 8

Laboratory Methods

	
<h1>Laboratory Procedures</h1> <p>CSUS: Volume 1 Chapter 9</p>	

Objectives

- Laboratory Units
- Laboratory Equipment & Techniques
- Laboratory Safety
- Water Quality Tests
 - Instrument – Based Tests
 - Tests for Plant Processes
 - Biological Tests
- Sampling

Right-to-Know

- Requires employers to inform and train workers about hazardous chemicals and substances in the workplace
- Employers must:
 - Provide workers with effective information and training on hazardous chemicals in their work area
 - Keep a current list of hazardous chemicals that are in the workplace
 - Make sure that hazardous chemical containers are properly labeled with the identity of the hazardous chemical and appropriate hazard warnings;
 - Have and make available to workers and their representatives Safety Data Sheets (SDSs) for each substance that provide detailed information about chemical hazards, their effects, how to prevent exposure, and emergency treatment if an exposure occurs.

TN Design Criteria Part 6 Laboratory Facilities

- 6.2 LABORATORY SPACE AND FACILITIES
 - 6.2.1 Laboratory facilities shall be located in a separate room from office/lunch activities and from the treatment units. Facilities shall be isolated by doors and not be located in the main traffic pattern.
 - 6.2.2 Sufficient bench space, adequate ventilation, adequate lighting, storage room, laboratory sink, and auxiliary facilities shall be provided.
 - 6.2.3 The bacteriological laboratory, if provided, shall have about 6-10 feet of counter space and shall be located in a separate room or area.

TN Design Criteria

Part 6 Laboratory Facilities

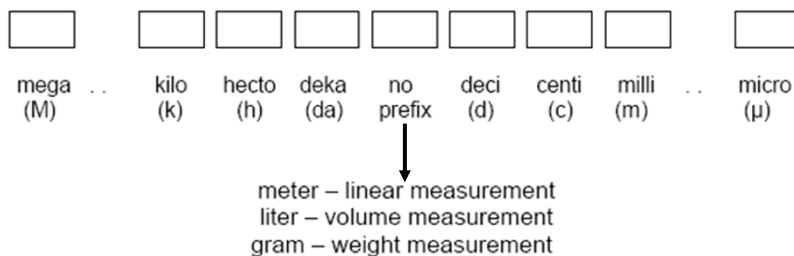
- 6.3 SAMPLE TAPS - Sample taps shall be provided so that water samples can be obtained from each water source and from appropriate locations in each unit operation of treatment. Taps shall be consistent with sampling needs and not be of petcock type. Sample lines and pumps where applicable shall be sized to minimize time lag between point of sampling and point of sample collection.

Laboratory Units



Laboratory Units

- The Metric System



Laboratory Units

- Chemical Names and Formulas

- Elements

- A substance that cannot be separated into its constituent parts and still retain its chemical identity

Aluminum	Al	Fluorine	F	Manganese	Mn
Calcium	Ca	Hydrogen	H	Oxygen	O
Carbon	C	Iron	Fe	Potassium	K
Chlorine	Cl	Lead	Pb	Sodium	Na
Copper	Cu	Magnesium	Mg	Sulfur	S

Laboratory Units

- Chemical Names and Formulas

- Compound (organic / inorganic)

- A substance composed of two or more elements whose composition is constant

- Examples:

Aluminum sulfate	$\text{Al}_2(\text{SO}_4)_3$
Calcium carbonate	CaCO_3
Hypochlorous acid	HOCl

- Ions

- Molecules with an electric charge either positive or negative
 - Many compounds dissociate in water to form ions

- Examples:

$\text{CaCO}_3 \rightarrow \text{Ca}^{2+} + \text{CO}_3^{2-}$
$\text{HOCl} \rightarrow \text{H}^+ + \text{OCl}^-$

Laboratory Equipment & Techniques

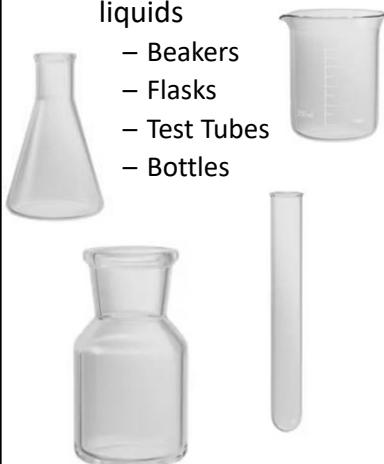


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Laboratory Equipment & Techniques

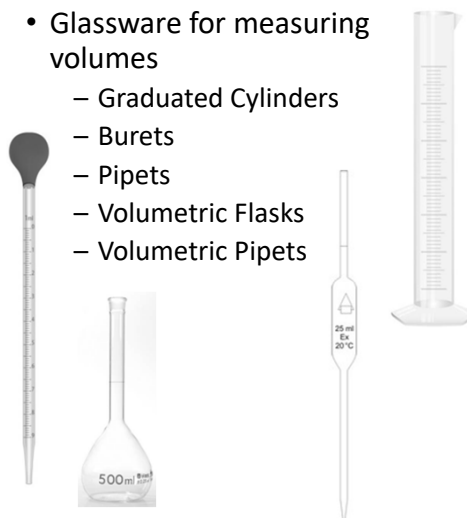
- Vessels for containing liquids

- Beakers
- Flasks
- Test Tubes
- Bottles



- Glassware for measuring volumes

- Graduated Cylinders
- Burets
- Pipets
- Volumetric Flasks
- Volumetric Pipets



Special – Purpose Glassware

- Filter Flasks
- Membrane Filter Holder
- Funnel



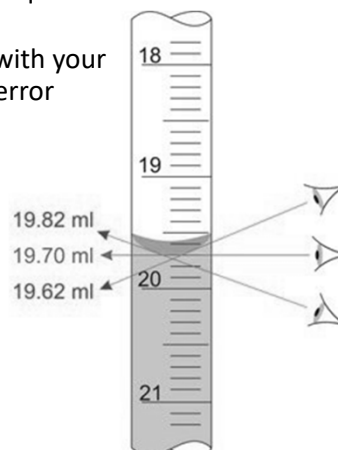
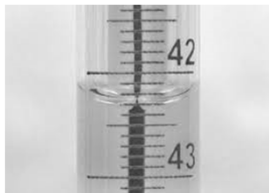
General Laboratory Equipment

- Tongs and Clamps
- Magnetic Stirrers
- Bunsen Burners
- Analytical Balances
- Autoclaves



Using Laboratory Glassware

- Reading Volumes
 - Meniscus – curved surface of a column of liquid in a small tube
 - Always read the bottom of the meniscus with your eye at the same level to prevent parallax error



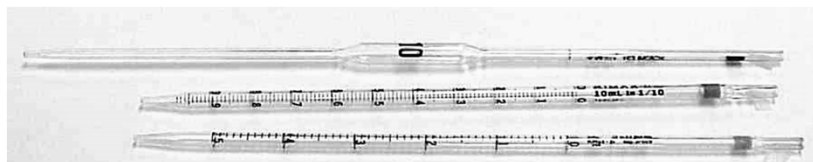
Using Laboratory Glassware

- Using Pipets
 - To Deliver or To Contain (TD or TC)
 - A small drop of liquid will stick in tip of pipet
 - If TD – volume does not include drop; leave the drop there
 - If TC – volume includes the drop, and it must be added



Using Laboratory Glassware

- Using Pipets
 - 3 types
 - Volumetric pipets – deliver a single volume very accurately
 - Measuring pipets – deliver fractions of the total volume indicated on the pipet
 - Serological pipets
 - Graduated (Mohr) pipets



Chemical Solutions

- Mass Concentration (mg/L)
 - The mass of a constituent contained in a liter of solution
 - Approximately 1 part per million (ppm)
- Standard solution
 - A solution in which the exact concentration of a chemical is known
- Standardization
 - Using one solution of known concentration to determine the concentration of another solution
 - Involves Titration
 - Addition of a chemical solution of known concentration drop by drop until a certain endpoint is reached

Chemical Solutions

- Molar concentration
 - Mole (mol) is a unit of measurement for the number of atoms or molecules
 - Examples: H_2O – 1 mol of water
 $7(\text{H}_2\text{O})$ – 7 mol of water
- Molecular weight
 - The sum of the atomic weights of the elements in the compound
 - Molarity \approx molecular weight
 - Example: $\text{H}_2\text{O} = 2 \times 1\text{g (H)} + 1 \times 16\text{g (O)} = 18\text{ g}$
- Normality (N)
 - Contains 1 equivalent weight of compound per liter of solution

Laboratory Equipment & Techniques

- Data Recording & Recordkeeping
 - Notebooks and worksheets help you record data in an orderly manner
 - Operators should create their own worksheets
- Laboratory Quality Control
 - Poor data quality caused by
 - Sloppy lab technique, deteriorated reagents/standards, poorly operating equipment, calculation mistakes

Laboratory Safety



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Laboratory Hazards

- Corrosive materials
 - Acids: muriatic acid (HCl), hydrofluoric (HF), glacial acetic (H_3COOH), nitric (HNO_3), sulfuric (H_2SO_4)
 - Bases: sodium hydroxide (NaOH), quicklime (CaO), hydrated lime ($\text{Ca}(\text{OH})_2$)
 - Miscellaneous: alum, chlorine,
- Toxic materials
 - Solids: heavy metals
 - Liquids: organic solvents
 - Gases: chlorine, ammonia, chlorine dioxide
- Explosive or Flammable materials
 - Liquids: acetone, ethers, and gasoline
 - Gases: propane, hydrogen, methane

Personal Hygiene & Safety

- Never work alone in the laboratory
- Wear protective goggles or eyeglasses at all times in the lab
 - Contact lenses are not recommended in the lab
- Know location and operation of safety showers and eyewash stations
- Never pipet by mouth
- Always wear a lab coat or apron and disposable gloves
- Wear insulated gloves when handling hot objects
- Do not bring food, drink, or tobacco into lab
- Exercise good housekeeping
- Wear close-toed shoes when in the lab

Preventing Laboratory Accidents

- Chemical Storage
 - Good housekeeping is a significant contribution to safety
 - Clearly label and date all chemicals and reagent bottles
 - Safety Data Sheet (SDS) – essential part of OSHA's Globally Harmonized System (GHS) of Classification and Labeling of Chemicals
 - Store acids and bases in separate storage cabinets
- Moving Chemicals
 - When transporting cylinders of compressed gas, use a trussed hand truck; never roll cylinder
 - Always wear protective gloves, safety shoes, and rubber aprons in case of accidental spill

Proper Laboratory Techniques

- Always rinse outside of acid bottles before pouring acid
- Keep all acids tightly stoppered while not in use
 - Always add acid to water; never add water to acid
 - Minimizes heat production and subsequent splashing
- Use a disposable pipet/dropper to collect mercury beads
 - Dispose of properly (*not the trash can*)
- Never pour *any* hazardous material down a drain
- Labeling
 - Any chemical that is not labeled is considered hazardous and disposal costs are high
 - Even temporary labels must meet OSHA's GHS standard

Accident Prevention

- Electric Shock
 - Ground all apparatus using a three-pronged plug
 - All permanent wiring installed by electrician with proper conduit or BX (armored) cable to prevent overloading
- Cuts
 - Inspect glassware for cracks, scratches, or defects before use
 - Use two hands when carrying glassware
- Burns
 - Use gloves and tongs to prevent burns from hot glass
 - Chemical burns originate from spattering acids, caustic materials, and strong oxidizing agents
 - Keep vinegar and soda handy to neutralize acids and bases

Accident Prevention

- Toxic Fumes
 - Use ventilated fume hood for volatile reagent preparation
 - Make sure fume hood is properly vented outdoors
- Waste Disposal
 - Never pour hazardous material down a drain
 - Corrosives damage pipes, flammables can volatilize and ignite;
 - Dispose of hazard materials in accordance with local or state regs
 - Provide dedicated trash receptacle for broken glass

Accident Prevention

- Fire
 - Lab should have fire blanket for clothing fires
 - Larger fires promptly require fire extinguisher
 - Small fires in dishes can be put out by covering dish
 - Do not use extinguisher on fire in small dish as it will knock it over
 - Fire extinguisher classified same as fires (A, B, C, D)
 - Class A – Ordinary Combustibles (wood, rubber, plastics, grass, etc.)
 - Uses water, soda-acid, carbon dioxide gas
 - Class B – Flammable & Combustible Liquids (gas, tar, paint, etc.)
 - Uses foam, carbon dioxide, or dry chemical extinguisher
 - Class C – Energized Electrical Equipment (breaker, motor, etc.)
 - Uses carbon dioxide, or dry chemical extinguisher
 - Class D – Combustible Metals (magnesium, sodium, potassium, etc.)
 - Uses fine dry soda ash, sand, or graphite

Water Quality Tests



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Instrument-Based Water Quality Tests



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Temperature

- Important due to influence on chemical reaction rates, biological growth, dissolved gas concentrations, and water viscosity
- Types of Thermometers
 - Liquid-in-glass – temperature indicated by expansion of a liquid; typically, mercury or alcohol
 - Total Immersion
 - Partial Immersion
 - Dial – has dial that actuated by differential expansion of two different metal strips joined together
 - Digital – based on measuring voltage across an element whose resistance varies with temperature

Temperature – Testing Procedure

1. Collect as large a volume of sample as practical
 - This minimize the temperature changing
2. Immerse the thermometer to the proper depth
 - Do not touch the bottom or sides of the container with the thermometer
3. Record temperature to nearest fraction of degree that can be estimated from thermometer
4. Temperature of distribution system samples depend mainly on soil temperatures at the depth of the main
 - To get an accurate reading of this temperature, allow water to continuously overflow a small container
 - Place thermometer in cup
 - Record temperature after there has been no change in more than a minute

pH

- *Power of Hydrogen*
- Negative logarithm of the hydrogen ion activity
$$\text{pH} = -\log [\text{H}^+]$$
- An expression of the intensity of the basic or acidic condition of a liquid
- pH scale runs from 0 to 14
- @ pH of 7 = neutral solution
- @ pH > 7 = basic or alkaline solution
- @ pH < 7 = acidic solution
- Sometimes measured in standard units (s.u.)

pH

- Hydrogen activity is equal to its molar concentration
- Acids have many H^+ ions; bases have few
- Bases have many OH^- ; acids have few
- If $\text{pH} = 1$, then the hydrogen ion activity would be 10^{-1} or 0.1 mol/L,
- If $\text{pH} = 14$, then $\text{H}^+ = 10^{-14}$ and $\text{OH}^- = 10^0$
- If $\text{pH} = 4$, then $\text{H}^+ = 10^{-10}$ and $\text{OH}^- = 10^{-4}$
- In a solution, both H^+ and OH^- ions are always present

pH

- Approximate pH measurements can be made using a colorimetric method
 - e.g. litmus paper
- Accurate pH lab measurements are done with an electrochemical probe
 - Meter reads voltage difference between two internal electrodes
 - *Ion Selective Electrode (ISE)*

pH – Testing Procedure

- Standardize instrument (pH meter) against a buffer solution with a pH close to that of the same, or with buffers over a range
 - *Must use at least 2 buffers that are 3 units away from each other*
 - Prepare fresh buffers daily
- Rinse electrodes thoroughly with distilled or deionized water between samples
- Place electrodes in sample and measure pH
- Remove electrodes from sample, rinse thoroughly with DI water
- Immerse electrode tip in solution of pH buffer 7 storage solution

pH

- pH meter, buffer solution and samples should all be close in temperature
- Erratic results may be the result of problems with the ISE, faulty connections, or fouling of electrodes with oil precipitated matter
 - Follow manufacturer's instructions
- pH of water may change with temperature (*entire scale shifts*)
 - Temperature compensator in pH meter adjusts for changes in electrode response with temperature

Influences of pH

- Disinfection
 - As pH increases, disinfection efficiency decreases
 - $\text{HOCl} \rightarrow \text{H}^+ + \text{OCl}^-$
 - A chlorine residual of 0.2 mg/L at pH 7 has same effectiveness as a chlorine residual of 1.0 mg/L at pH 10
- Corrosion Control
 - Determines if the finished water is aggressive and needs to be adjusted with lime or caustic
- Sedimentation
 - Chemical coagulation has optimal pH in which it operates

Turbidity

- Physical cloudiness of water caused by
 - Suspended matter such as silt
 - Finely divided organic and inorganic matter
 - Microscopic organisms
- Measured with the nephelometric method
 - Nephelometric turbidity meter or nephelometer measures light reflected by particles
 - The greater intensity of scattered light the greater the turbidity
- Safe Drinking Water Act (SDWA) specifies monitoring requirements of surface water or GWUI systems
 - Must be measured every 4 hours or continuously
 - Results must be reported

Turbidity

- Turbidity units (TU) based on amount of light scattered at a 90° angle by particles in a standard
 - Formazin Turbidity Units (FTU)
 - Nephelometric Turbidity Units (NTU)
 - Most common in water treatment
- Primary standards are a suspension of formazin, an insoluble polymer formed by a particular reaction
 - *Used for calibration to be performed every 3 months*
- Secondary standards are suspensions of various materials formulated to match the primary formazin solutions
 - *Used for daily verification (gel standards)*

Turbidity Procedure

- Turbidimeter Calibration
 - Follow manufacturer's operating instructions
 - Measure standard solutions that cover range of interest
 - At least one standard should be run in each instrument range to be used
 - Reliance on an instrument manufacturer's scattering standards for calibrating the instrument is not an acceptable practice
 - *I think they mean gel standards*

Turbidity Procedure

- Measurement
 - Sample tubes must be scrupulously clean inside and out; do not handle where light shines
 - Samples should be measured as soon as possible; shaking sample will not re-create original turbidity
 - Holding time: 15 minutes
 - Samples should be agitated enough to assure that all particles are suspended but not so much to introduce air bubbles
 - Degas samples with vacuum, surfactants, or ultrasonic bath
 - Do not dilute samples

Titration-Based Tests Alkalinity

- A measure of the water's capacity to neutralize acids
- Caused by ions
 - hydroxide (OH^-)
 - carbonate (CO_3^{2-})
 - bicarbonate (HCO_3^-)
- Carbonate and hydroxide ions react with hydrogen ions to neutralize
 - $\text{OH}^- + \text{H}^+ \rightarrow \text{H}_2\text{O}$
 - $\text{CO}_3^{2-} + \text{H}^+ \rightarrow \text{HCO}_3^-$
 - $\text{HCO}_3^- + \text{H}^+ \rightarrow \text{H}_2\text{CO}_3$
- Not all hydrogen ions are consumed so pH still drops, slowly
 - OH^- is consumed by pH 10
 - CO_3^{2-} is consumed by pH 8.3
 - HCO_3^- is consumed by pH 4.5

Titration-Based Tests Alkalinity

- Titrate sample with an acid until you reach the predetermined endpoint
 - Titrating to pH 4.5 measures total alkalinity (TA)
 - Titrating to pH 8.3 measures phenolphthalein alkalinity (PA)
- Expressed in terms of calcium carbonate equivalents
 - mg/L as CaCO_3
- What is tested
 - Raw and treated surface water 20 - 300 mg/L as CaCO_3
 - Well water 80 - 500 mg/L as CaCO_3
- Precautions
 - Analyze samples as soon as possible
 - Do not agitate, warm, filter, dilute, concentrate or alter the sample

Influences of Alkalinity

- Many chemicals used in water treatment act as acids or bases and can change the pH of water is insufficiently buffered
 - alum
 - chlorine
 - Lime
- Coagulation and Flocculation
 - Reactions between alkalinity minerals and coagulants are what create insoluble flocs
- Corrosion Control
 - Carbonate is a necessary part of calcium carbonate

Titration-Based Tests Hardness

- Caused principally by the calcium and magnesium ions present in water
- Defined as the total concentration of calcium and magnesium ions expressed as the calcium carbonate equivalent
- 2 classifications
 - Carbonate (temporary)
 - Noncarbonate (permanent)
- Ca and Mg can precipitate and form solid incrustations (scale) in filters and distribution system
- Scale composed mainly of
 - Calcium carbonate
 - Magnesium hydroxide
 - Calcium sulfate

Titration-Based Tests Hardness

- Reagents
 - Buffer solution
 - Standard EDTA titrant (Disodium ethylene-diaminetetraacetate dihydrate)
 - Indicator solution (Endochrome Black T (EBT) or Calmagite)
- Procedure
 - Take clean beaker and add 50 mL of sample water
 - Add 1-2 mL of buffer solution
 - Add 1-2 drops of indicator solution
 - Titrate with EDTA until the last reddish tinge has disappeared and a pure blue color reached
 - Calculate total hardness in mg/L as CaCO_3

Titration-Based Tests Hardness

- Precautions
 - Some metal ions interfere by causing fading or indistinct endpoints; inhibitor reagents should be used in these cases
 - Titration should be completed within 5 minutes to minimize CaCO_3 precipitation
 - Sample volume selected should require less than 15 mL of titrant to be used
 - For titrations of samples containing low hardness concentrations (less than 150 mg/L) a larger sample volume should be used

Titration-Based Tests Chlorine Residual

- Disinfectant that also reacts with iron, manganese, protein substances, sulfide and many T&O producing compounds
- Two types of residual chlorine
 - Free residual chlorine
 - Chlorine gas (Cl_2)
 - Hypochlorous acid (HOCl)
 - Hypochlorite ion (OCl^-)
 - Combined residual chlorine
 - Monochloramine (NH_2Cl)
 - Dichloramine (NHCl_2)
 - Trichloramine (NCl_3)
- Adverse effect: can produce potentially carcinogenic chlororganic compounds
 - THMs and HAA_5

Titration-Based Tests Chlorine Residual

- Amperometric Titration
 - PAO (phenylarsine oxide) is added to reduce residual chlorine to chloride (Cl^-)
 - Titrator measures electrical current through sample
 - When all chlorine has reacted with PAO, the current stops
 - This is the endpoint of the titration
 - Residual chlorine concentration is proportional to the PAO added
- DPD Titrimetric Method
 - DPD reacts with free chlorine to produce a red color
 - Titrate sample with FAS (ferrous ammonium sulfate) to make color disappear
 - This is the endpoint of the titration

Titration-Based Tests Chlorine Residual

- DPD Colorimetric Method
 - N,N-diethyl-p-phenylenediamine (DPD) reacts with free chlorine to produce a red color in proportion to the chlorine concentration
 - An electronic instrument is used to measure the intensity of the color
 - Visual comparison between the sample color and a standard



INCOMPLETE

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Section 9

Process Chemistry

AWWA: Basic Science Concepts and Applications



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Chemistry of Treatment Processes

Taste and Odor Removal



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Taste and Odor Removal

- Difficult to remove
 - Many different materials may cause T&O
 - No common treatment can remove all types of T&O
 - Tests used to measure are subjective
- Tools for measuring
 - Threshold odor number (TON) test
 - Flavor profile analysis
- Tools for removal
 - Physical removal
 - Chemical oxidation

Taste and Odor Removal

- Physical Removal
 - Coagulation followed by filtration
 - Adsorption
- Chemical Oxidation
 - T&O materials converted chemically to non-T&O causing compounds
 - Oxidizing agents
 - Oxygen
 - Chlorine
 - Potassium permanganate
 - Chlorine dioxide
 - Ozone

Oxygen

- Mixed into water by aeration
- Effectively removes iron, manganese, hydrogen sulfide
- Hydrogen sulfide (H_2S)
 - H_2S is converted to elemental sulfur that can be coagulated and filtered out
 - Water will have milky-blue color
 - Removed best at pH = 4.5
 - Add CO_2 to lower pH prior to aeration
 - Sulfur can be converted to sulfate (SO_4^{-2})
 - Sulfate can be converted back to H_2S in anaerobic conditions

Chlorine

- Algae caused odors, iron & manganese, and hydrogen sulfide can be successfully oxidized
- Chlorine can intensify certain tastes and odors
 - Phenolic (medicinal) compounds
 - Caused by organic compounds
 - Earthy odors
 - Caused by algae and actinomycetes
- Prechlorination should be avoided if humic acid (natural organic produced by decaying vegetation) is present
 - Prevent THM formation

Permanganate

- Effective in removing iron and manganese and oxidizing organic and inorganic T&O causing materials
- Reaction in water produces
 - Oxygen (oxidizes organics and inorganics)
 - Manganese dioxide (MnO_2) to be removed during conventional treatment
- Add to water early for detention time (1-5 hours)
- Water turns pink when treated
 - As permanganate creates MnO_2 , color will change
 - Pink \rightarrow yellow \rightarrow orange \rightarrow brown
 - All pink should be gone before filtration to minimize yellow-brown water from oxidation

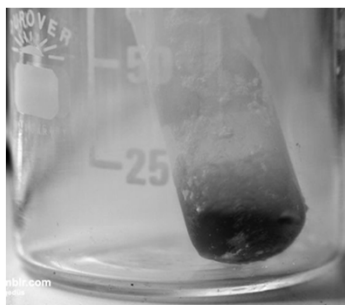
Chlorine Dioxide

- Strong oxidizing agent used primarily to control odors caused by phenolic compounds
- Must be made on site by mixing sodium chlorite with a concentrated chlorine solution



Ozone

- Ozonation can be effective in taste and odor control but varies depending on quality of water to be treated
- O_3 generated onsite by releasing electric spark into stream of oxygen
- Strong oxidizer



Coagulation



Alum

- Aluminum Sulfate $[\text{Al}_2(\text{SO}_4)_3 \bullet 14\text{H}_2\text{O}]$
- Most widely used coagulant
- Two forms:
 - Filter alum
 - Ivory white solid available in lump, ground, rice, or powdered form
 - Liquid alum
 - Already in solution
 - Strongest available is less than half the strength of dry filter alum

Alum

- $\text{Al}_2(\text{SO}_4)_3 + 3\text{Ca}(\text{HCO}_3)_2 \rightarrow 2\text{Al}(\text{OH})_3\downarrow + 3\text{CaSO}_4\downarrow + 6\text{CO}_2$

alum	natural	aluminum	calcium	carbon
	bicarbonate	hydroxide	sulfate	dioxide
	alkalinity	floc		
- $\text{Al}_2(\text{SO}_4)_3 + 3\text{Na}_2\text{CO}_3 + 3\text{H}_2\text{O} \rightarrow 3\text{Al}(\text{OH})_3\downarrow + 3\text{Na}_2\text{SO}_4 + 3\text{CO}_2$

alum	added	aluminum	sodium	carbon
	carbonate	hydroxide	sulfate	dioxide
	alkalinity	floc		
- $\text{Al}_2(\text{SO}_4)_3 + 3\text{Ca}(\text{OH})_2 \rightarrow 2\text{Al}(\text{OH})_3\downarrow + 3\text{CaSO}_4\downarrow$

alum	added	aluminum	calcium
	hydroxide	hydroxide	sulfate
	alkalinity	floc	

Alum

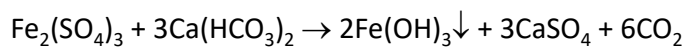
- Alum coagulation occurs in three steps:
 - Positively charged aluminum ions (Al^{+3}) attract the negatively charged particles to form microfloc
 - Positively charged microfloc attract and hold more negatively charged color-causing and turbidity-causing material
 - Microfloc grows into easily visible, mature floc particles
 - Attraction of color and turbidity materials
 - Adsorption of viruses, bacteria, and algae
 - Random collision of particles
- Large floc particles are later settled out

Alum

- Dose depends on water qualities
 - Typically ranges from 15-100 mg/L
- Effective pH range 5.8-8.5
- Floc formation varies with temperature
 - Lower temp means slower floc formation
 - Compensate by increasing dosage
- Use jar tests to evaluate dosage for varying water quality

Ferric Sulfate

- Reddish-gray or grayish-white granule



ferric natural ferric calcium carbon
sulfate bicarbonate hydroxide sulfate dioxide
 alkalinity floc

- Alkalinity is required to form floc (ferric hydroxide)
- Floc is denser than when using alum
- Effective pH range of 3.5-9.0
- Can react with organics to form soluble iron (red water)
- Doses typically range from 5-50 mg/L

Iron and Manganese Removal

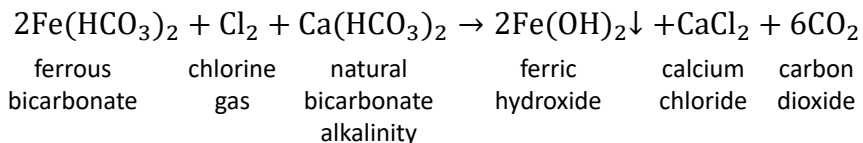


Iron and Manganese Removal

- Fe and Mn found primarily in groundwater and occasionally in anaerobic hypolimnion of deep reservoirs
- Ferric (Fe^{+3}) and manganic (Mn^{+4}), the insoluble forms, exist naturally
 - Converted to soluble forms, ferrous (Fe^{+2}) and manganous (Mn^{+2}) in anaerobic conditions
- Most removal processes work to oxidize the reduced forms into their insoluble forms to be settled out

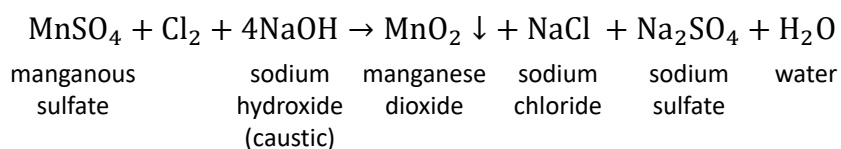
Chlorine

- Chlorine reaction with ferrous bicarbonate [$\text{Fe}(\text{HCO}_3)_2$] is almost instantaneous
 - Works at pH 4-10 with optimal at pH 7
 - 0.64 mg/L of chlorine required to remove 1.0 mg/L of iron (Fe^{+2})
 - Ferric hydroxide produced



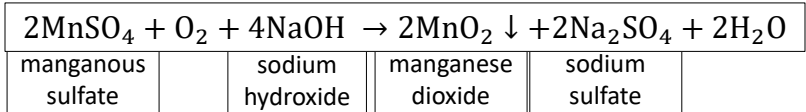
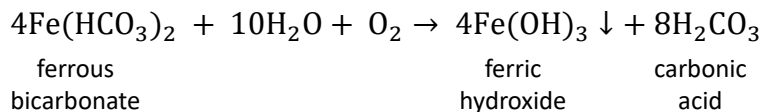
Chlorine

- Chlorine reacts with manganous sulfate similarly
 - 1.3 mg/L of chlorine must be added per 1 mg/L of manganese
 - Best pH range 6-10
 - Higher pH = faster reaction



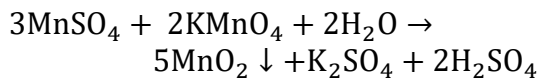
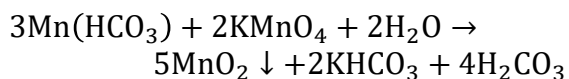
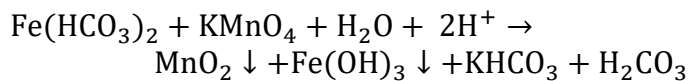
Aeration

- Ferrous iron (Fe^{+2}) and manganous manganese (Mn^{+2}) can be removed by aeration
- Iron removal is a two-step process
 - Ferrous iron \rightarrow Ferrous hydroxide \rightarrow Ferric hydroxide
 - Works best in pH range 7.5-8.0
 - 0.14 mg/L oxygen required to remove 1 mg/L



Permanganate

- Potassium permanganate is strong oxidizer that can remove both iron and manganese (preferred method)



Lime-Soda Ash Softening



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Types of Hardness

- Carbonate hardness
 - Caused by salts of calcium bicarbonate $\text{Ca}(\text{HCO}_3)_2$
- Noncarbonate hardness
 - Caused by salts of calcium & magnesium
 - Calcium sulfate, CaSO_4
 - Calcium chloride, CaCl_2
 - Magnesium chloride, MgCl_2
 - Magnesium sulfate, MgSO_4

Noncarbonate Hardness

- To remove magnesium noncarbonate hardness

$$\text{MgCl}_2 + \text{Ca}(\text{OH})_2 \rightarrow \text{Mg}(\text{OH})_2 \downarrow + \text{CaCl}_2$$

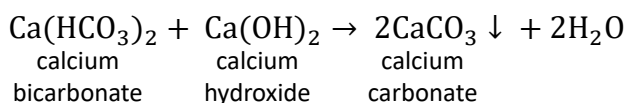
magnesium chloride	lime	magnesium hydroxide	calcium chloride
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- Calcium noncarbonate hardness is formed

$$\text{CaCl}_2 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3 \downarrow + 2\text{NaCl}$$

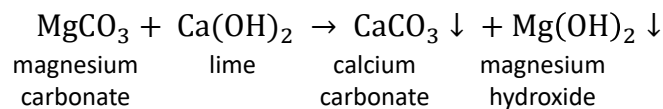
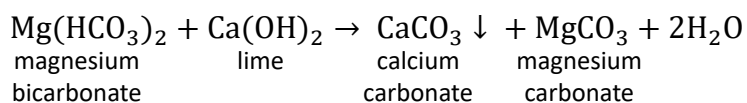
calcium chloride (from previous equation)	soda ash	calcium carbonate	sodium chloride
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Carbonate Hardness

- Only lime is required
- To remove calcium bicarbonate

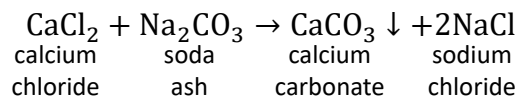
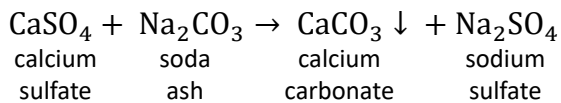


- To remove magnesium carbonate hardness



Noncarbonate Hardness

- Soda ash removes noncarbonate calcium compounds
- Soda ash plus lime removes noncarbonate magnesium compounds
- To remove calcium noncarbonate hardness



Lime-Soda Ash Softening

Main hardness causing ions

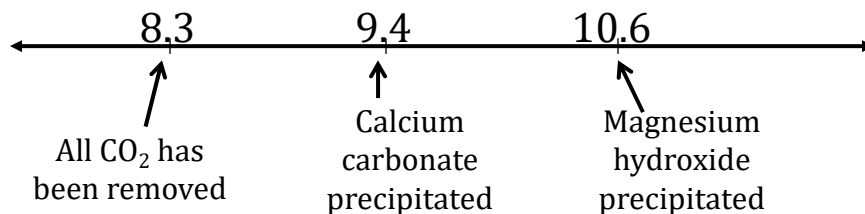
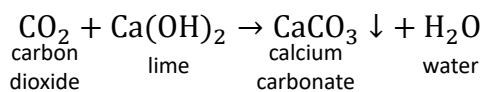
- Calcium (Ca^{+2})
- Magnesium (Mg^{+2})

Chemical precipitation commonly used to soften water

- Lime - $\text{Ca}(\text{OH})_2$; calcium hydroxide
 - Used to remove carbonate hardness
- Soda ash – Na_2CO_3 ; sodium carbonate
 - Used to remove noncarbonate hardness

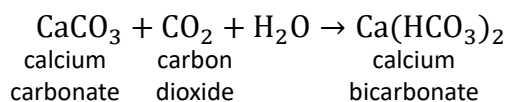
Carbon Dioxide

- Gas found in dissolved form in most natural waters
- Will react with lime before softening reaction takes place



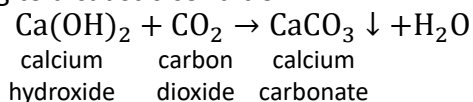
Recarbonation

- Reintroduction of CO₂ into the water either during or after lime-soda ash softening
- Lime softened water becomes supersaturated with calcium carbonate which will precipitate at the high pH caused by the lime
- CO₂ is bubbled into the water lowering the pH and removing the CaCO₃

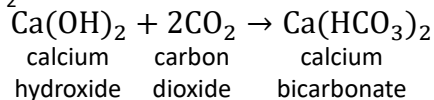


Recarbonation

- Excess lime treatment leaves considerable amount of lime in water leading to a caustic condition



- If too much CO₂ is added



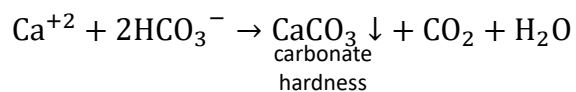
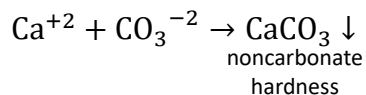
Scaling and Corrosion Control



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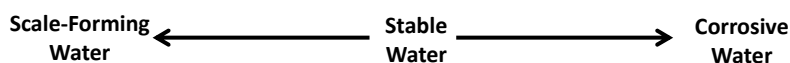
Scaling & Corrosion Control

- Objective is to stabilize the water thus preventing scale formation and corrosion
- Scale caused by carbonate and noncarbonate hardness
 - White, chalky deposit
 - Can be beneficial if controlled
 - Can reduce capacity of pipelines and efficiency of boilers if excessive



Scaling and Corrosion Control

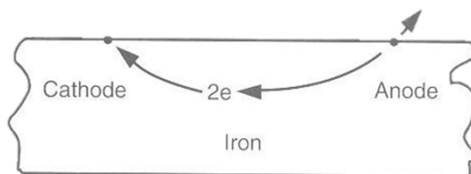
- Corrosion is oxidation of unprotected metal surfaces
- Iron and its alloys are primary concern in drinking water
 - Identified by rust
 - Elemental iron (which pipes are made of) is unstable and tends to return to more stable ore forms by oxidation or corrosion



- Water will either be corrosive or scale forming
 - It cannot be both

Scaling and Corrosion Control

- Corrosion is a complex process that can be influenced by several factors
- When iron corrodes, it is converted from elemental iron (Fe) to ferrous iron (Fe^{+2})



Chemical Methods for Scale and Corrosion Control

Method	Scale	Corrosion
pH and alkalinity adjustment with lime	X	X
Chelation (natural sequestering)	X	
Sequestering	X	
Controlled CaCO ₃ scaling		X
Other protective chemical coatings		X
Softening	X	

pH and Alkalinity Adjustment with Lime

- CO₂ present in the form of carbonic acid
- pH will increase

- 1 mg/L of lime fed will remove 0.56 mg/L of CO₂

$$\underset{\substack{\text{carbonic} \\ \text{acid}}}{\text{H}_2\text{CO}_3} + \underset{\text{lime}}{\text{Ca}(\text{OH})_2} \rightarrow \underset{\substack{\text{calcium} \\ \text{carbonate}}}{2\text{CaCO}_3} + 2\text{H}_2\text{O}$$

- For each mg/L of lime, alkalinity will increase by 1.28 mg/L

$$\underset{\substack{\text{calcium} \\ \text{bicarbonate}}}{\text{Ca}(\text{HCO}_3)_2} + \underset{\text{lime}}{\text{Ca}(\text{OH})_2} \rightarrow \underset{\substack{\text{calcium} \\ \text{carbonate}}}{2\text{CaCO}_3} + 2\text{H}_2\text{O}$$

pH and Alkalinity Adjustment with Lime

- Lime dose too high → excessive scale formation
- Lime dose too low → corrosive water
- Langelier Saturation Index
 - Based on assumption that every water has a particular pH value for which the water will neither deposit scale nor cause corrosion
 - Stable condition called saturation
 - Saturation pH or pH_s varies depending on calcium hardness, alkalinity, and temperature

$$LSI = pH - pH_s$$

pH and Alkalinity Adjustment with Lime

- If actual pH < pH_s , then LSI is negative
 - Water is corrosive
- If actual pH > pH_s , then LSI is positive
 - Water is scale forming

Corrosive Characteristics	Langelier Saturation Index (LSI)
Highly Aggressive	< -2.0
Moderately Aggressive	-2.0 to 0.0
Non-aggressive	> 0.0

Chelation

- Chemical treatment process used to control scale formation
 - Chelating agent is a water-soluble compound that captures scale-causing ions in solution, prevent precipitation and scale formation
 - Reacts with calcium ions in water to keep them in solution and prevent the formation of CaCO_3 scale
- $$2\text{Ca}^{+2} + \text{Na}_4\text{Y} \rightarrow \text{Ca}_2\text{Y} + 4\text{Na}^+$$
- Y represents the chelating agent



Sequestration

- Chemical treatment process that controls scale
- Chemical sequestrants (holds on to) scale-causing ions preventing them precipitating forming scale
 - Calcium, iron, manganese
- Any of several polyphosphates can be used
 - Sodium hexametaphosphate $[(\text{NaPO}_3)_6]$ most common
- Sequestration is deliberate addition of chemicals to drinking water
 - Chelation is often considered a natural process

Controlled CaCO_3 Scaling

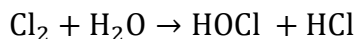
- By controlling pH and alkalinity that, condition of water can be altered
 - Slightly scale-forming
 - Creates a coating, but will continue to grow and eventually clog pipe
 - Slightly corrosive
 - Will dissolve the excess scale
- Must monitor incoming water quality data to determine lime feed amount
- Must monitor CaCO_3 thickness
 - Thick enough to provide coating without restricting flow

Chlorination

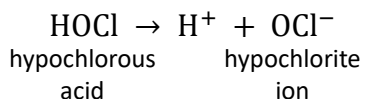


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Reaction in Pure Water



- Hypochlorous acid is a weak acid that will dissociate as pH increases



- Hypochlorite ion works as disinfecting agent, only significantly (100x) weaker than HOCl
- These reactions will lead to lower pH

Chlorination Effectiveness Based On

- pH
 - Low pH favors formation of HOCl
 - High pH favors formation of OCl^-
 - Leads to increased contact time
- Temperature
 - Lower temperatures
 - Slightly favor formation of HOCl
 - Allow residual to persist longer
 - Higher temperatures favor chlorination
 - Chemical and biological reactions happen faster at higher temperatures

Chlorination Effectiveness Based On

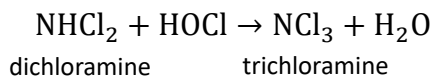
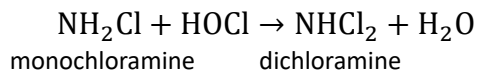
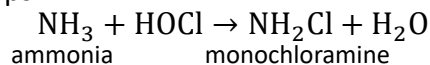
- Contact time
- Concentration
- Other substances in the water
 - Reducing agents
 - Ammonia (NH₃)
 - Iron (Fe)
 - Manganese (Mn)
 - Hydrogen sulfide (H₂)
 - Dissolved organic materials



Most important factors

Reaction with Ammonia (NH₃)

- Inorganic compound occurring naturally as a result of decaying vegetation or artificially from domestic and industrial wastewater discharges
- Chlorine reacts with ammonia to form chloramines in three successive steps

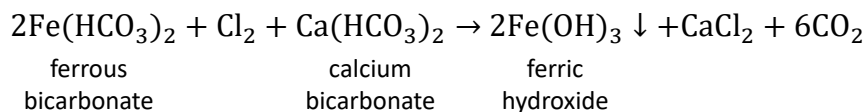


Reaction with Ammonia (NH₃)

- Combined chlorine (monochloramine & dichloramine) are less effective disinfecting agents than free chlorine
- Combined chlorine is less effective as an oxidizing agent than free chlorine
- Free chlorine will always react with any available ammonia first creating combined chlorine
 - This combined chlorine will slow the oxidation of the other reducing agents considerably
 - Must feed 25 times more combined chlorine than free to obtain the same bactericidal results

Reaction with Iron

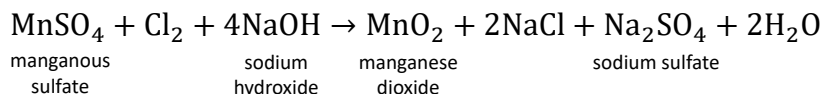
- Often found in groundwater as ferrous bicarbonate [Fe(HCO₃)₂]
- Easily removed by chlorination



- Ferric hydroxide precipitates as a fluffy, rust colored sludge
- 1 mg/L of iron requires 0.64 mg/L of chlorine to remove it

Reactions with Manganese

- Found in groundwater in form of a soluble salt
 - Manganous sulfate
 - May cause brown or black water

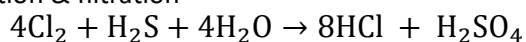


- Each 1 mg/L of manganese requires 1.3 mg/L of free chlorine to remove it
 - Not affected by combined chlorine
- Minimum reaction time of 2 hours required

Reaction with Hydrogen Sulfide (H₂S)

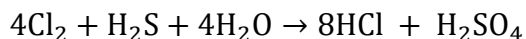
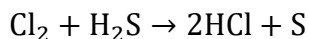
- Frequently found in groundwater sources
 - Can impact taste at 0.05 mg/L
 - Rotten egg smell at 0.5 mg/L
 - Fatal if inhaled at 0.1-0.2% concentration in air
 - Flammable above 4.3% concentration in air
- Chlorine reacts with H₂S in one of two ways depending pH

$$\text{Cl}_2 + \text{H}_2\text{S} \rightarrow 2\text{HCl} + \text{S}$$
 - Instantaneous reaction that occurs at high pH
 - Formed sulfur causes milky-blue turbidity that can be removed by coagulation & filtration



preferred
reaction

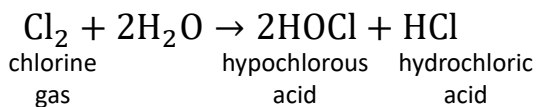
Reaction with Hydrogen Sulfide (H₂S)



- If pH \approx 6.4, all sulfides are converted to sulfates
- At pH \approx 7.0, 70% of H₂S turns to H₂SO₄ and other 30% turns to elemental sulfur
- At pH \approx 9.0-10.0, 50% H₂S turns to H₂SO₄ and 50% turns to elemental sulfur (S)

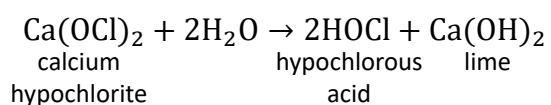
Sources of Chlorine

- Gaseous chlorine (Cl₂)
 - Liquid chlorine is a gas that is compressed into an amber colored liquid
 - 100% pure chlorine
 - Liquid will expand 460 to volume to become gas
 - Greenish-yellow gas and highly toxic
 - Will not burn, but will support combustion
 - Gaseous chlorine is 2.5 times heavier than air



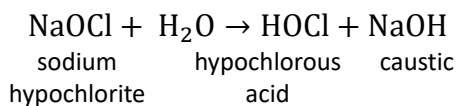
Sources of Chlorine

- Calcium hypochlorite [Ca(OCl)₂]
 - Dry, white granular material available in tablets
 - 65% chlorine by weight
 - Store carefully to avoid contact with easily oxidized organic materials
 - Can cause fires



Sources of Chlorine

- Sodium hypochlorite (NaOCl)
 - Clear, greenish-yellow liquid chlorine solution



Section 10

Feed Rate Math

Chemical Feeders



Mass

- Mass is a measurement of how much matter is in an object
 - Mass always stays the same while weight changes with gravity
 - On Earth, mass will be the same as weight

$$\text{mass, lbs} = (\text{volume, MG}) \left(\text{concentration, } \frac{\text{mg}}{\text{L}} \right) \left(8.34 \frac{\text{lb}}{\text{gal}} \right)$$

Feed Rate

- When adding chemicals to the water flow, a measured amount of chemical is required that depends on such factors as the type of chemical being used, the reason for dosing and the flow rate being treated.

$$\text{loading rate, } \frac{\text{lb}}{\text{day}} = (\text{flow, MGD})(\text{conc., } \frac{\text{mg}}{\text{L}}) (8.34 \frac{\text{lb}}{\text{gal}})$$

Example 1

- Jar tests indicate that the best alum dose for a water is 8 mg/L. If the flow to be treated is 2,100,000 gpd, what should the lb/day setting be on the dry alum feeder?

$$\text{loading rate, } \frac{\text{lb}}{\text{day}} = (\text{flow, MGD}) \left(\text{conc., } \frac{\text{mg}}{\text{L}} \right) \left(8.34 \frac{\text{lb}}{\text{gal}} \right)$$

$$\frac{\text{lb}}{\text{day}} = (2.10 \text{ MGD})(8 \frac{\text{mg}}{\text{L}})(8.34 \frac{\text{lb}}{\text{gal}})$$

$$\frac{\text{lb}}{\text{day}} = 140 \frac{\text{lb}}{\text{day}}$$

Example 2 (ABC Formula Book)

- An operator collects three 1-minute samples of lime from the dry feeder. The weights collected are 5 grams, 7 grams and 5 grams, respectively. Determine the average feed rate in lbs/day.

$$\text{average} = \frac{5\text{g} + 7\text{g} + 5\text{g}}{3} = \frac{17\text{g}}{3} = 5.67\text{grams}$$

$$\left(\frac{5.67\text{ grams}}{1\text{ minute}}\right) \left(\frac{60\text{ min}}{1\text{ hr}}\right) \left(\frac{24\text{ hr}}{1\text{ day}}\right) \left(\frac{1\text{ kg}}{1000\text{ g}}\right) \left(\frac{1\text{ lb}}{0.454\text{ kg}}\right)$$

$$\frac{(5.67)(60)(24)(1)(1)}{(1)(1)(1)(1000)(0.454)} = \frac{8164.8}{454}$$

$$17.98\text{ lb/day}$$

Example 2 (again with FTC formula book)

- An operator collects three 1-minute samples of lime from the dry feeder. The weights collected are 5 grams, 7 grams and 5 grams, respectively. Determine the average feed rate in lbs/day.

$$\text{average sample mass, gram} = \frac{5\text{g} + 7\text{g} + 5\text{g}}{3} = \frac{17\text{g}}{3} = 5.67\text{grams}$$

$$\text{avg feed rate, } \frac{\text{g}}{\text{min}} = \frac{5.67\text{g}}{1\text{ min}} = 5.67 \frac{\text{g}}{\text{min}}$$

$$\text{avg feed rate, } \frac{\text{lb}}{\text{day}} = \frac{(5.67 \frac{\text{g}}{\text{min}})(1440 \frac{\text{min}}{\text{day}})}{453.6 \frac{\text{g}}{\text{lb}}}$$

$$\text{avg feed rate, } \frac{\text{lb}}{\text{day}} = 18\text{ lb/day}$$

Chemical Solution Feeder Setting

- When solution concentration is expressed as lb chemical per gallon solution (lb/gal), the required feed rate can be determined
 - Use the lb/day formula and convert it to gal/day when specific weight (or density) is different than water

$$\text{feed rate, gal/day} = \frac{\text{chemical feed rate, lb/day}}{\text{lb chemical/gal solution}}$$

Example 3

- Jar tests indicate that the best alum dose for a water is 7 mg/L. The flow to be treated is 1.52 MGD. Determine the gallons per day setting for the alum solution feeder if the liquid alum contains 5.36 lbs of alum per gallon of solution.

$$\begin{aligned} \text{Loading Rate } \frac{\text{lb}}{\text{day}} &= (\text{flow, MGD})(\text{conc, mg/L})(8.34 \text{ lb/gal}) \\ \frac{\text{lb}}{\text{day}} &= (1.52 \text{ MGD})(7 \text{ mg/L})(8.34 \text{ lb/gal}) \\ \frac{\text{lb}}{\text{day}} &= 88.7376 \text{ lb/day} \end{aligned}$$

Example 3 Cont'd

- Chemical Solution Feeder Setting
- "...the liquid alum contains 5.36 lbs of alum per gallon of solution."

$$\frac{\text{gal}}{\text{day}} = \left(\frac{88.7376 \text{ lb}}{1 \text{ day}} \right) \left(\frac{1 \text{ gal solution}}{5.36 \text{ lb chemical}} \right)$$

$$\text{gpd} = \frac{(88.7376)(1)}{(1)(5.36)}$$

$$\text{gpd} = 16.6 \text{ gal/day}$$

Chemical Feed Pump Setting

- Some solution chemical feeders dispense chemical as millimeters per minute (mL/min).

$$\frac{\text{mL}}{\text{min}} = \frac{(\text{Flow, MGD})(\text{dose, } \frac{\text{mg}}{\text{L}}) \left(3.785 \frac{\text{L}}{\text{gal}} \right) (1,000,000 \frac{\text{gal}}{\text{MG}})}{(\text{liquid, } \frac{\text{mg}}{\text{mL}}) \left(1440 \frac{\text{min}}{\text{day}} \right)}$$

**If percent purity is provided, divide final number by decimal

Example 4

- A flow of 2.12 MGD is to be treated with a solution of chemical. The desired dose is 1.4 mg/L. The chemical to be fed weighs 1175.5 mg/mL. What should be the mL/min solution feed rate?

$$\frac{\text{mL}}{\text{min}} = \frac{(\text{Flow, MGD})(\text{dose, } \frac{\text{mg}}{\text{L}}) \left(3.785 \frac{\text{L}}{\text{gal}}\right) (1,000,000 \frac{\text{gal}}{\text{MG}})}{(\text{liquid, } \frac{\text{mg}}{\text{mL}}) \left(1440 \frac{\text{min}}{\text{day}}\right)}$$

$$\frac{\text{mL}}{\text{min}} = \frac{(2.12 \text{MGD})(1.4 \frac{\text{mg}}{\text{L}})(3.785 \frac{\text{L}}{\text{gal}})(1,000,000 \frac{\text{gal}}{\text{MG}})}{(1175.5 \frac{\text{mg}}{\text{mL}})(1440 \frac{\text{min}}{\text{day}})}$$

$$\frac{\text{mL}}{\text{min}} = \frac{11,233,880 \text{mg}}{1692720 \frac{\text{mg} \cdot \text{min}}{\text{mL}}} = 6.64 \frac{\text{mL}}{\text{min}}$$

Chemical Feed Pump Setting

- Chemical feed pumps are generally positive displacement pumps (e.g. piston pumps)
- This type of pump displaces, or pushes out, a volume of chemical equal to the volume of the piston
- The length of the piston, called the stroke, can be lengthened or shortened to increase or decrease the amount of chemical delivered by the pump

$$\% \text{ stroke} = \frac{\text{desired flow}}{\text{maximum flow}} \times 100$$

Example 5

- The required chemical pumping rate has been calculated as 8 gpm. If the maximum pumping rate is 90 gpm, what should the percent stroke setting be?

$$\% \text{ stroke} = \frac{\text{desired flow}}{\text{maximum flow}} \times 100$$

$$\% \text{ stroke} = \frac{8 \text{ gpm}}{90 \text{ gpm}} \times 100$$

$$\% \text{ stroke} = 8.9\%$$

Applied Math for Water Treatment

Chemical Feeders

Practice Problems

1. A water plant fed 130 lbs of alum each day to treat 1.3 MGD. Calculate the dose in mg/L.

2. The average flow for a water plant is 3.25 MGD. A jar test indicates that the best alum dosage is 2.5 mg/L. How many pounds per day will the operator feed?

3. Jar tests indicate that the best liquid alum dose for a water unit is 11 mg/L. The flow to be treated is 2.13 MGD. Determine the gallons per day setting for the liquid alum chemical feeder if the liquid alum is a 60% solution. Assume the alum solution weighs about 8.34 lb/gal.

4. Jar tests indicate that the best liquid alum dose for a water unit is 10 mg/L. The flow to be treated is 4.10 MGD. Determine the gallons per day setting for the liquid alum chemical feeder if the liquid alum contains 5.88 lbs of alum per gallon of solution.

5. A water treatment plant used 14 pounds of cationic polymer to treat 2.0 million gallons of water during a 24-hour period. What is the polymer dosage in mg/L?

6. A water treatment plant used 27 pounds of cationic polymer to treat 1.6 million gallons of water during a 24-hour period. What is the polymer dosage in mg/L?
7. A jar test indicates the 4.3 mg/L of liquid alum is required in treating 6.7 MGD. How many mL/min should the metering pump deliver? The liquid alum delivered to the plant contains 645 mg alum per mL of liquid solution.
8. The operator measured the amount of dry chemical fed in one day as 114.5 lbs. How many grams/min should the dry feeder have delivered?
9. The maximum pumping rate is 110 gpm. If the required pumping rate is 40 gpm, what is the percent stroke setting?
10. The required chemical pumping rate has been determined to be 14 gpm. What is the percent stroke setting if the maximum rate is 70 gpm?
11. A jar test indicates the 3.4 mg/L of liquid alum is required in treating 7.6 MGD. How many mL/min should the metering pump deliver? The liquid alum delivered to the plant contains 645 mg alum per mL of liquid solution.

12. Liquid alum delivered to a water treatment plant contains 642.3 milligrams of alum per milliliter of liquid solution. Jar tests indicate that the best alum dose is 8 mg/L. Determine the setting on the liquid alum chemical feeder in milliliters per minute if the flow is 2.2 MGD.
13. An operator is checking the calibration on a chemical feeder. The feeder delivers 102 grams in 5 minutes. How many pounds per day does the feeder deliver?
14. The average flow for a water plant is 8.3 MGD. A jar test indicates that the best alum dosage is 2.2 mg/L. How many grams per minute should the feeder deliver?
15. You collect three 2-minute samples from an alum dry feeder. What is the feed rate in lb/day when the flow rate is 2 MGD?
 - a. Sample 1 = 25 grams
 - b. Sample 2 = 22 grams
 - c. Sample 3 = 24 grams
16. A water plant used 167 gallons of a liquid chemical in one day. How many mL/min was pumped?

17. The average daily flow for a water plant is 7.5 MGD. Jar test results indicate the best polymer dosage is 1.8 mg/L. How many pounds of polymer will be used in 90 days?
18. Liquid alum delivered to a water treatment plant contains 642.3 milligrams of alum per milliliter of liquid solution. Jar tests indicate that the best alum dose is 15 mg/L. Determine the setting on the liquid alum chemical feeder in milliliters per minute when the flow is 7.2 MGD. There are 3.785 liters in one gallon.
19. A pond has an average length of 250 ft, an average width of 75 ft and an average depth of 10 ft. If the desired dose of copper sulfate is 0.8 lbs/acre-ft, how many pounds of copper sulfate will be required?
20. Jar tests indicate that the best alum dose for a water unit is 8 mg/L. The flow to be treated is 1,440,000 gpd. Determine the gallons per day setting for the liquid alum chemical feeder if the liquid alum contains 6.15 lb of alum per gallon of solution.
21. The required chemical pumping rate has been calculated to be 22 gpm. If the maximum pumping rate is 80 gpm, what should the percent stroke setting be?

22. An operator collects 3 two-minute samples from a dry feeder to check the calibration. What is the average feed rate in lb/day?
- a. Sample 1 weighs 47.3 grams
 - b. Sample 2 weighs 44.8 grams
 - c. Sample 3 weighs 42.4 grams
23. A water plant is treating 1.8 MGD with 2.0 mg/L liquid alum. How many gpd of liquid alum will be required? The liquid alum contains 5.36 lbs dry alum/gallon.
24. An operator checks the calibration of a dry feeder by catching samples and weighing them on a balance. Each catch lasts 1 minute. Based on the following data, what is the average feed rate in lb/hour?
- a. Sample 1 weighs 37.0 grams
 - b. Sample 2 weighs 36.2 grams
 - c. Sample 3 weighs 39.4 grams
 - d. Sample 4 weighs 38.6 grams
25. The flow to the plant is 4,440,000 gpd. Jar testing indicates that the optimum alum dose is 9 mg/L. What should the gallons per day setting be for the solution feeder if the alum solution is 60% solution. Assume the solution weighs 8.34 lb/gal.

26. KMnO_4 has been made according to the manufacturer recommendations (30 mg/mL). The water plant operator wants to dose 3.6 MGD with 2.0 mg/L KMnO_4 . How many mL/min must be delivered by the metering pump?
27. Determine the setting on a dry alum feeder in pounds per day when the flow is 1.3 MGD. Jar tests indicate that the best alum dose is 12 mg/L.
28. The required chemical pumping rate has been calculated to be 30 gpm. If the maximum pumping rate is 80 gpm, what should the percent stroke setting be?
29. An operator collects 5 two-minute samples from a dry feeder. What is the average feed rate in lb/day?
- a. Sample 1 weighs 49.2 grams
 - b. Sample 2 weighs 44.0 grams
 - c. Sample 3 weighs 41.9 grams
 - d. Sample 4 weighs 48.3 grams
 - e. Sample 5 weighs 47.6 grams
30. Determine the setting on a dry alum feeder when the flow is 5.4 MGD. Jar tests indicate that the best alum dose is 8 mg/L. What would be the setting in grams per minute?

31. A water plant is treating 8.2 MGD with 2.0 mg/L liquid alum. How many gpd of liquid alum will be required? The liquid alum contains 5.36 lbs dry alum/gallon.
32. The average daily flow for a water plant is 0.75 MGD. If the polymer dosage is kept at 1.8 mg/L, how many pounds of polymer will be used in 30 days?
33. A chemical feeder feeds a liquid chemical to a 1000 mL graduated cylinder for 48 seconds. At the end of the 48 seconds, the graduated cylinder is completely full. What is the chemical feed rate for the metering pump in gallons per day?
34. An operator collects 3 two-minute samples from a dry feeder. What is the average feed rate in lb/day?
- a. Sample 1 weighs 22.2 grams
 - b. Sample 2 weighs 24.0 grams
 - c. Sample 3 weighs 21.9 grams
35. A water plant treats 3.5 MGD with a dose of 2.2 mg/L KMnO_4 . If the water plant uses 257 gallons of permanganate per day, how many mL/min must be pumped?

36. For algae control of a reservoir, a dosage of 0.5 mg/L copper is desired. The reservoir has a volume of 20 MG. How many pounds of copper sulfate (25% available copper) will be required?
37. A jar test indicates that 1.8 mg/L of liquid ferric chloride should be fed to treat 2,778 gpm of water. How many mL/min should be fed by a metering pump? Ferric chloride contains 4.59 lbs dry chemical per gallon of liquid solution.
38. Liquid polymer is supplied to a water treatment plant as an 8% solution. How many gallons of liquid polymer should be used to make 55 gallons of a 0.5% polymer solution?
39. The average flow for a water plant is 13.5 MGD. The jar test indicates that the best alum dose is 1.8 mg/L. How many pounds per day will the operator feed?
40. A water plant fed 52 grams per minute of dry alum while treating 2.6 MGD. Calculate the mg/L dose.

41. The average flow for a water plant is 6.3 MGD. A jar test indicates that the best alum dosage is 19 mg/L. How many pounds per day will the operator feed?

42. The average flow for a water plant is 8,890 gpm. A jar test indicates that the best polymer dose is 3.1 mg/L. How many pounds will the plant feed in one week? (Assume the plant runs 24 hour/day, 7 days/week.)

43. A water plant fed 48.5 grams per minute while treating 2.2 MGD. Calculate the mg/L dose.

44. The desired copper sulfate dose in a reservoir is 5 mg/L. The reservoir has a volume of 62 acre-ft. How many lbs of copper sulfate (25% available copper) will be required?

Answers

- | | | |
|-------------------|--------------------|------------------------|
| 1.) 11.99 mg/L | 16.) 438.95 mL/min | 31.) 25.52 gal/day |
| 2.) 67.76 lb/day | 17.) 10,133.1 lb | 32.) 337.77 lb |
| 3.) 39.05 gal/day | 18.) 441.97 mL/min | 33.) 22,826.95 gal/day |
| 4.) 58.15 gal/day | 19.) 3.44 lb | 34.) 72.06 lb/day |
| 5.) 0.84 mg/L | 20.) 15.62 gal/day | 35.) 67.08 mL/min |
| 6.) 2.02 mg/L | 21.) 27.5% | 36.) 333.6 lb |
| 7.) 117.41 mL/min | 22.) 71.16 lb/day | 37.) 34.61 mL/min |
| 8.) 36.07 g/min | 23.) 5.60 gal/day | 38.) 3.44 gal |
| 9.) 36.36% | 24.) 5 lb/hr | 39.) 202.66 lb/day |
| 10.) 20% | 25.) 66.6 lb/day | 40.) 7.61 mg/L |
| 11.) 105.3 mL/min | 26.) 630.83 mL/min | 41.) 998.3 lb/day |
| 12.) 72.02 mL/min | 27.) 130.10 lb/day | 42.) 2,316.52 lb |
| 13.) 64.76 lb/day | 28.) 37.5% | 43.) 8.39 mg/L |
| 14.) 47.97 g/min | 29.) 13.33 lb/day | 44.) 3,371.36 lb |
| 15.) 37.56 lb/day | 30.) 113.49 g/min | |