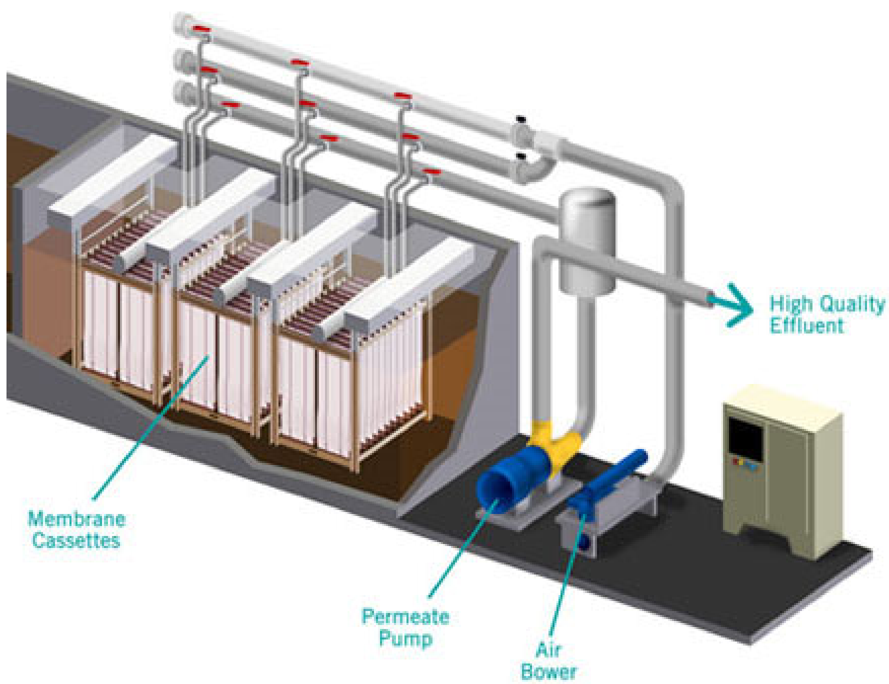
Advanced Water Treatment

Course # 3110



Fleming Training Center
Your Partner in Clean Water

TN Department of Environment & Conservation

Updated 7-2023

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Chemistry

Chemistry

AWWA: Basic Science Concepts and Applications

Objectives

- Structure of Matter
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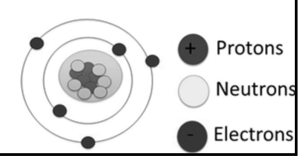
- Chemistry of Treatment Processes

Structure of Matter

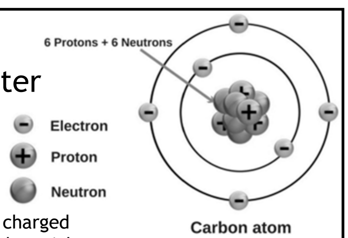
AWWA: Basic Science Concepts and Applications

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



Structure of Matter



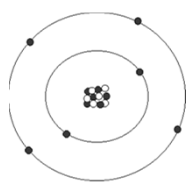
- Nucleus
  - Center of atom
  - Made up of positively charged protons and uncharged particles called neutrons
- Electrons
  - Occupy space surrounding nucleus
  - Make up most of the volume of the atom
  - Occupy space in "shells"

Structure of Matter

6
C
Carbon
12.011

- 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

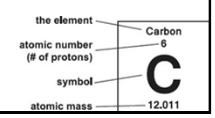
Structure of Matter



- 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:
  - Atomic weight
  - Element symbol
  - Element name
  - Atomic number



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	57 *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	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110	111 111	112 112	113 113					

* 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

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Classification of Matter

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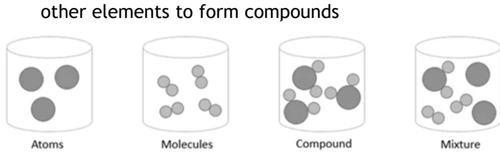
Classification of Matter

- 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

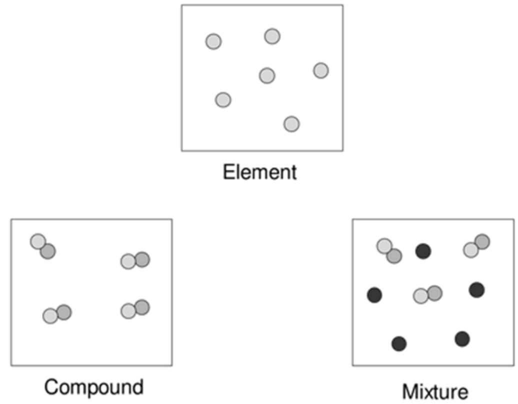


Classification of Matter

- 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

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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

$CaCO_3$

Ca C O O O

$Ca(HCO_3)_2$

Ca HCO_3 HCO_3

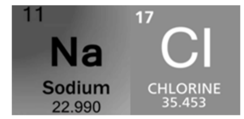
Calcium bicarbonate contains:
1 calcium atom
2 hydrogen atoms
2 carbon atoms
6 oxygen atoms

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



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

$CaCO_3$

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

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

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

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

$$100.00\%$$

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 may 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

calcium bicarbonate	plus	calcium hydroxide	reacts to form	calcium carbonate	plus	water
$Ca(HCO_3)_2$	+	$Ca(OH)_2$	→	$2CaCO_3$	+	$2H_2O$

Reactants (calcium bicarbonate plus calcium hydroxide) — Products (calcium carbonate plus water)

- "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

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$$

Chemical Equations

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

  $Ca(HCO_3)_2$ = 162.12
  $Ca(OH)_2$ = 74.10
  $CaCO_3$ = 100.09
  100.09 x 2 = 200.18
  H_2O = 18.02
  18.02 x 2 = 36.04

$Ca(HCO_3)_2$	+	$Ca(OH)_2$	→	$2CaCO_3$	+	$2H_2O$
162.12		74.10		200.18		36.04

- Given 162.12 lb of $Ca(OH_2)$, you must add 74.10 lb of $Ca(HCO_3)_2$ 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

$Ca(HCO_3)_2$	+	$Ca(OH)_2$	→	$2CaCO_3$	+	$2H_2O$
162.12		74.10		(2)(100.09)		(2)(18.02)
1 mol		1 mol		2 mol		2 mol

- 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)

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

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

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

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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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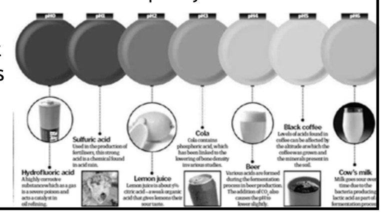
Acids

- 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*

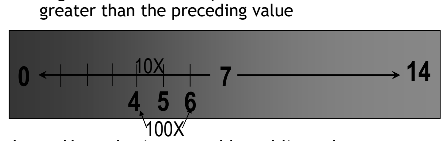


Bases and Salts

- 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
      $\mathrm{HCl} + \mathrm{NaOH} \rightarrow \mathrm{NaCl} + \mathrm{H_2O}$

pH

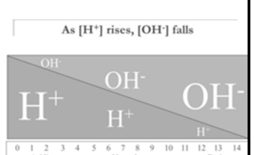
- A measurement of how acidic or basic a solution is
- pH scale runs from 0 (most acidic) to 14 (most basic)
  - Log scale means each pH measurement is 10 times greater than the preceding value



- 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 in *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 (CO_3^{-2}) alkalinity
  - Bicarbonate (HCO_3^-) 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^+

$$HCO_3^- + H^+ \rightarrow H_2CO_3$$

$$HCO_3^- \rightarrow H^+ + CO_3$$

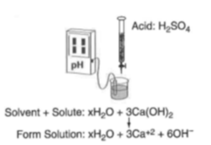
  - This maintains the water at around pH 7

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

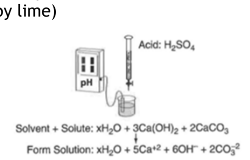
- Equal volumes of a base (lime) and water are mixed
- pH = 11
- All alkalinity is hydroxyl alkalinity



Solution 2

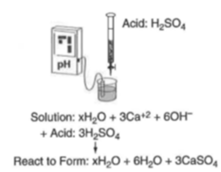
- Lime and calcium carbonate are mixed
- pH = 11

  (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)



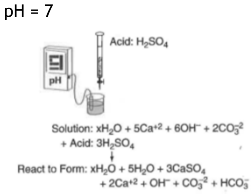
Solution 1

- 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



Periodic Table of the Elements

1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
1 **H** 1.00794																	2 **He** 4.002602
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											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
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]

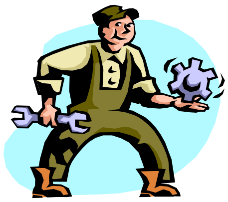
Section 2

Equipment Maintenance

Maintenance

California State University, Sacramento

Water Treatment Plant Operations Vol. II



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Treatment Plant Maintenance

- 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

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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

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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

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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.

Date	Work Done (Item No.)	Signed

Electrical Equipment

Beware of Electricity

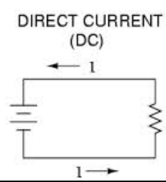
- Do not attempt to install, troubleshoot, maintain, repair, or replace electrical equipment, panels, controls, wiring, or circuits unless
  - You know what you are doing
  - You are qualified
  - You are authorized

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)

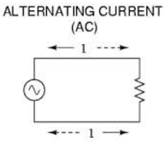
Direct Current (DC)

- 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



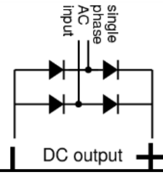
Alternating Current (AC)

- 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



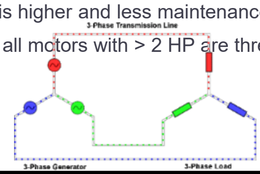
Alternating Current – Single Phase

- 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



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



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)

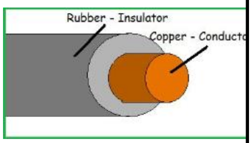
- The units of measurement of the rate at which power is being used or generated
- In DC circuits, watts equal the voltage times the current

  Watts = (volts)(amps)
- In AC polyphase circuits, you have to include the power factor and the $\sqrt{3}$

  Watts = (volts)(amps)(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

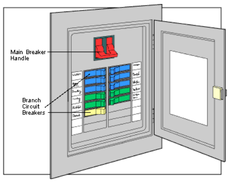
- Records the current or “amps” flowing in the circuit
- Two common types:
  - Clamp-on type – used for testing
    - Clamped around a wire supplying a motor
  - In-line type – installed in a panel or piece of equipment
    - Connected in line with the power lead or leads

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

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



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

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Fuses

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Circuit Breakers

- A protective device consisting of a switch that opens automatically when the current of the voltage exceeds or falls below a certain limit
- Can be reset unlike a fuse
- Can be visually inspected to find out if it has been tripped

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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 form 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

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Overload Relays

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Auxiliary Electrical Power

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

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

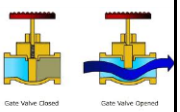
- Inspect the suction filter of the compressor monthly
  - Clean or replace filter every 3-6 months
- Lubrication must be inspected daily
  - Oil should be replaced every 3 months
- Cylinder or casing fins should be cleaned weekly
- Inspect unloader
  - If not working properly, compressor will not start,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

Compressor Maintenance

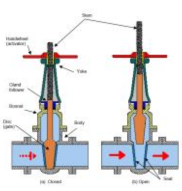
- Drain the condensate from air receiver daily
  - If has automatic drain, inspect periodically
- Inspect belt tension on compressor
  - Should be able to press the belt down, in the center, with your hand approximately ¾ inch
- Examine operating controls
  - Make sure compressor is starting and stopping 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 Valves – O & M

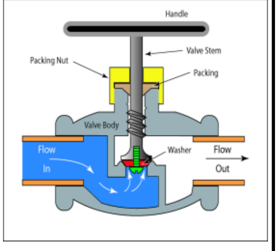
- 1. Open valve fully
- 2. Operate all large valves at least yearly to ensure proper operation
- 3. Inspect valve stem packing for leaks
- 4. If the valve has a rising stem, keep stem threads clean and lubricated
- 5. Close valves slowly in pressure lines to prevent water hammer
- 6. If a valve will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

Gate Valves - Maintenance

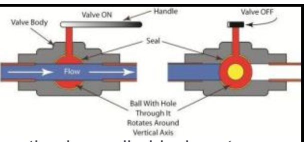
Frequency	Service
Annually	**Replace packing:** Remove all old packing from stuffing box. Insert new split ring packing while staggering the ring splits.
Semi-annually	**Operate valve:** Operate inactive gate valves to prevent sticking
Annually	**Lubricate gearing:** Lubricate gate valves as recommended 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 stiffing 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.

Globe Valves

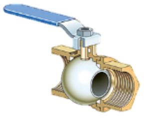
- Use a circular disc to make a flat surface contact with a ground-fitted valve seat
- Internal design enables valve to be used in a controlling /throttling mode
- Can be of rising or nonrising stem type
- O & M similar to gate valve



Ball Valves

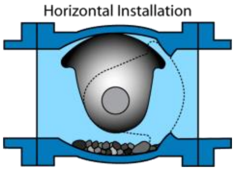


- A valve consisting of a ball resting in a cylindrical seat
- A hole is bored through the ball to allow water to flow when the valve is open
- When the valve is rotated 90°, the valve is closed
- Should be operated fully open or fully closed
  - Throttling can lead to damage to the seal



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



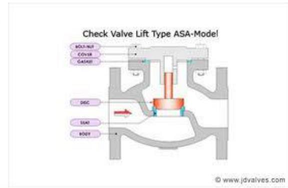
Butterfly Valves

- Used primarily as a control valve
- Uses a machined disc that can be opened to 90º 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 an 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



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

- Hydroscopic 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 crystalize 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

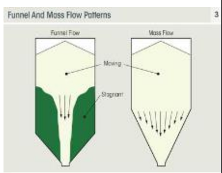
- Carbon should be stored in a clean, dry place
  - Single or double rows with access around every stack
  - Storage area should be fire proof with self closing fire doors
  - Should be protected from contact with flammable materials
  - Keep oily rags and chlorine compounds away from area

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

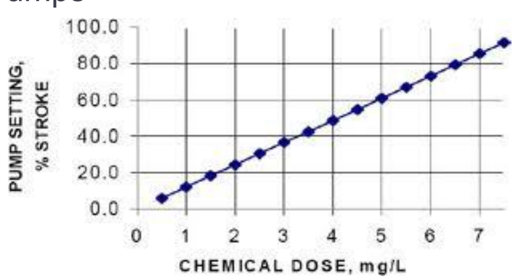
- Keep liquid feeders clean to prevent plugging or corrosion of the mechanism
- Single drain pit that can accept both acid and alkali chemicals is not allowed
- Solid chemical feeders should be kept clean and dry to prevent bridging of the chemical the hopper and clogging in the feeder
  - Bridging is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

Calibrating Large Volume Metering Pumps



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

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

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Maintenance Vocabulary

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

_____ 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 tow 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

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

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

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

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

TN

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

TN

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

TN

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)

TN

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 Mn2+. An alkaline-cyanide reagent is added to mask any potential interferences. PAN Indicator is then added to combine with the Mn2+ 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

TN

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

TN

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

TN

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

TN

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/ft^2 (Design Criteria 4.7.1 (c))

TN

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

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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

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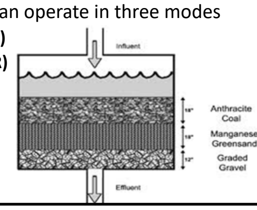
Oxidation with Permanganate

- 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**



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Manganese Greensand Filters

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TN Department of Environment & Conservation

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Conventional vs Manganese Greensand

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

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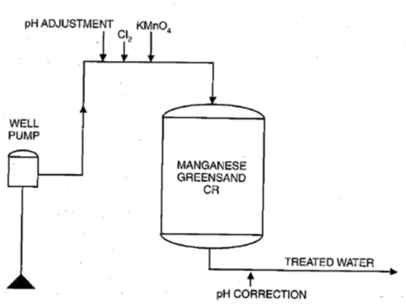

Fig. 12.5 Typical flow diagram of a continuous regeneration (CR) greensand process
(Permission of Hungerford & Terry, Inc.)

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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

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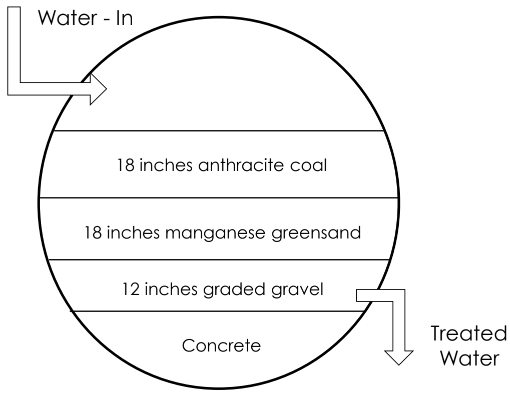

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Restrictions

- 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

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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

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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 $KMnO_4$

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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

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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

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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

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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.

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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.

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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

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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.

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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.

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Daily Testing

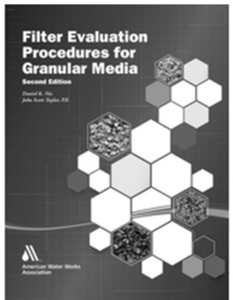
- Iron and manganese
  - Indicates that plant is operating at a level that meet state water quality requirements
- pH
  - Important due to relation between pH and corrosivity of the water
  - Needs to stay between 6.2 and 6.8 for effective Fe and Mn removal by the CR process
- Chlorine residual

Section 4

Filter Evaluation

FILTER EVALUATION PROCEDURE FOR GRANULAR MEDIA

AWWA
2nd Edition
Daniel K. Nix
John Scott Taylor, P.E.



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

LEVELS EXCEEDED

Depending on the exceedance level, the system must:

- 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

5

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…

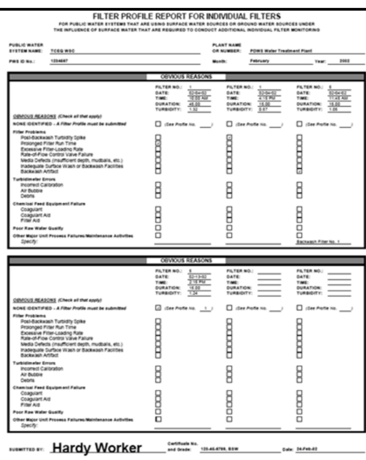
5. If there is a failure in the continuous turbidity monitoring equipment, the system must conduct grab sampling every four hours in lieu of continuous monitoring until the turbidimeter is repaired and back on-line. A system has a maximum of five working days after failure to repair the equipment or 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: TCEQ WSC

PLANT NAME OR NUMBER: POWS Water Treatment Plant

PWS ID No.: 1234567

Month: February Year: 2002

OBVIOUS REASONS

FILTER NO.:	1	1	6
DATE:	02-04-02	02-04-02	02-04-02
TIME:	10:00 AM	4:15 PM	11:45 AM
DURATION:	45.00	15.00	15.00
TURBIDITY:	1.32	0.67	1.06

OBVIOUS REASONS (Check all that apply)

NONE IDENTIFIED - A Filter Profile must be submitted ☐ (See Profile No. ___)

Filter Problems
- Post-Backwash Turbidity Spike
- Prolonged Filter Run Time
- Excessive Filter-Loading Rate
- Rate-of-Flow Control Valve Failure
- Media Defects (insufficient depth, mudballs, etc.)
- Inadequate Surface Wash or Backwash Facilities
- Backwash Artifact

Turbidimeter Errors
- Incorrect Calibration
- Air Bubble
- Debris

Chemical Feed Equipment Failure
- Coagulant
- Coagulant Aid
- Filter Aid

Poor Raw Water Quality

Other Major Unit Process Failures/Maintenance Activities

Specify: Backwash Filter No. 1

OBVIOUS REASONS

FILTER NO.:	6		
DATE:	02-13-02		
TIME:	2:15 PM		
DURATION:	15.00		
TURBIDITY:	1.24		

OBVIOUS REASONS (Check all that apply)

NONE IDENTIFIED - A Filter Profile must be submitted ☑ (See Profile No. 1)

Filter Problems
- Post-Backwash Turbidity Spike
- Prolonged Filter Run Time
- Excessive Filter-Loading Rate
- Rate-of-Flow Control Valve Failure
- Media Defects (insufficient depth, mudballs, etc.)
- Inadequate Surface Wash or Backwash Facilities
- Backwash Artifact

Turbidimeter Errors
- Incorrect Calibration
- Air Bubble
- Debris

Chemical Feed Equipment Failure
- Coagulant
- Coagulant Aid
- Filter Aid

Poor Raw Water Quality

Other Major Unit Process Failures/Maintenance Activities

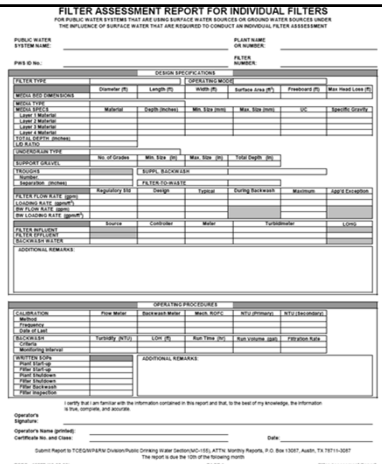
Specify:

SUBMITTED BY: Hardy Worker Certificate No. and Grade: 123-45-6789, DSW Date: 24-Feb-02

PAGE 1 FPR

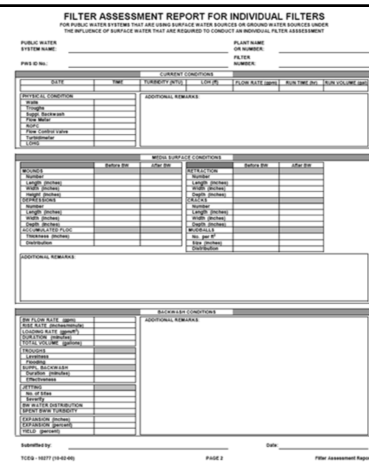
TENNESSEE PUBLIC WATER SYSTEMS 0400-45-01-.31(6)(b)(4)(ii)

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



FILTER ASSESSMENT REPORT FOR INDIVIDUAL FILTERS

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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

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 of 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

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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

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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

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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

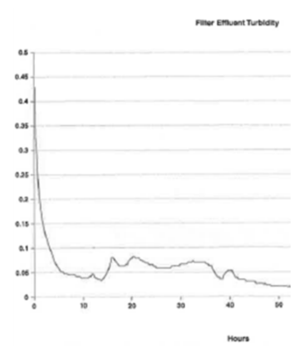
- Rubber boots
- Hard hat
- Safety rope or harness
- Ladder
- Ventilation equipment
- Expanded metal grating (if fluidizing filter bed)
- Buck and rope hoisting system
- Flashlight
- Radio/communication system

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

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

- Calculate and graph UFRV for each filter run to see trends

UFRV < 5,000 gal/ft^2 = short filter run times

UFRV > 10,000 gal/ft^2 = better performance

UFRV > 15,000 gal/ft^2 = good performance

FILTER EFFICIENCY

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

R_e = effective filtration rate (gpm/ft^2)
R_o = operating filtration rate(gpm/ft^2)
UFRV = unit filter run volume(gal/ft^2)
UBWV = unit backwash volume(gal/ft^2)

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 ≥ 1,000	for ordinary monosand or dual media beds

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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

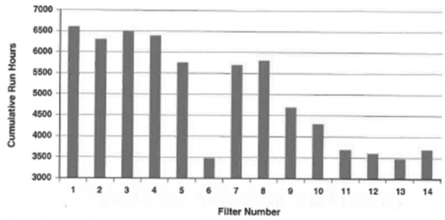
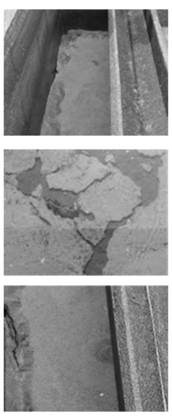


Figure 5-2 This is a run hour analysis of a "long filter corridor" indicating that the filters at the end of the corridor were not used as much as the filters at the beginning of the corridor. It also shows that Filter No. 6 was not as much as the filters on either side of it. This was due to a filter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

PHYSICAL OBSERVATIONS

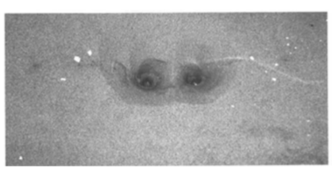
Chapter 6

PHYSICAL OBSERVATIONS



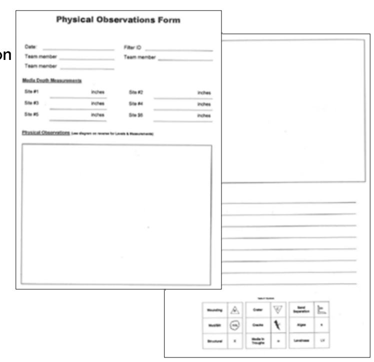
Observe surface of filter media as well as any appurtenances

- 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



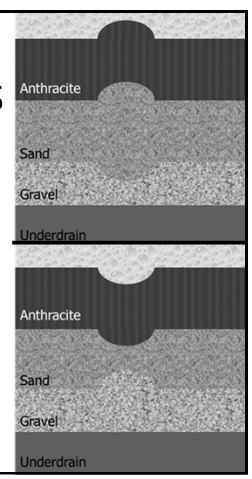
PROCEDURE

Prepare	Prepare form and draw filter lay out and troughs
Backwash	Backwash filter
Drain	Drain water from filter to below media surface
Enter	Enter filter (Do not step on media. Use plywood)
Note	Make note of any physical signs of filter distress

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

m/s

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

C

SS

e. Sand separation from walls
- Media separating from walls
- Insufficient backwash rate

NOTING FILTER CONDITIONS

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

a

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

X

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

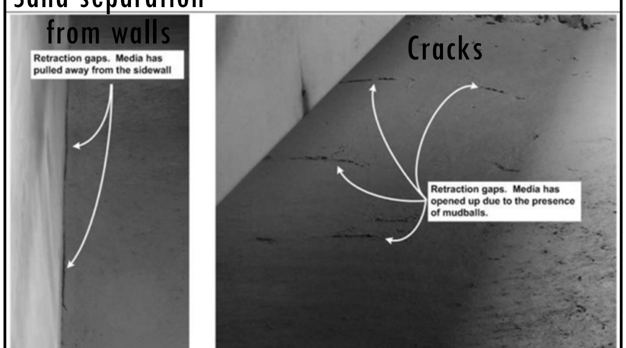
i. Media depth
- Using a punch rod, measure the media depth 5-6 times throughout the filter
- Make note/measurement of where measurements were taken

j. Levelness of wash-water troughs
- Using a carpenter's level, at both ends of trough and in middle, check levelness
  - Across width of trough
  - Down length of both sides
  - Between adjacent troughs
- Using water, observe if water passes over the troughs at same time

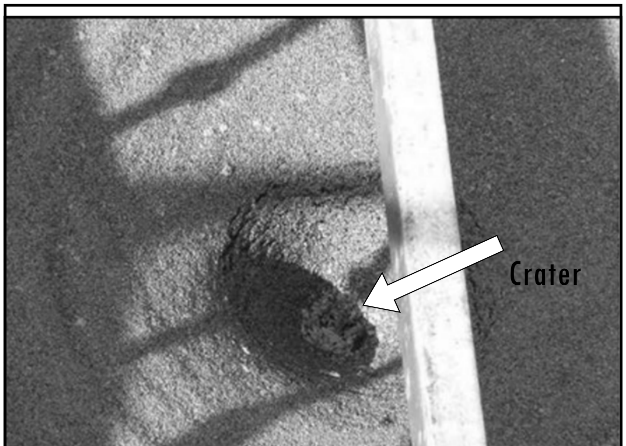
LV

k. Freeboard measurement
- Distance from top of trough to top of media surface
- Generally, 2 ft from media to bottom of trough is acceptable

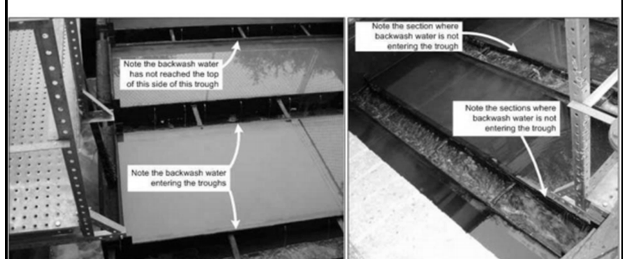
Sand separation from walls



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



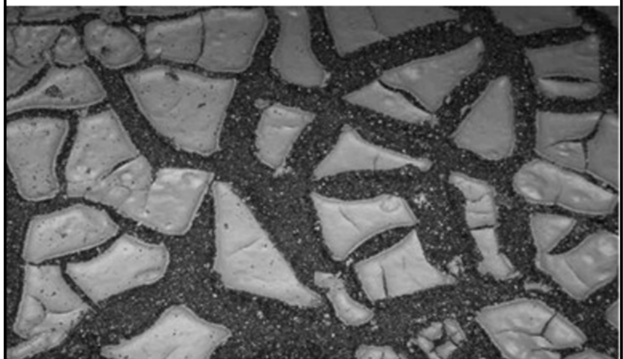
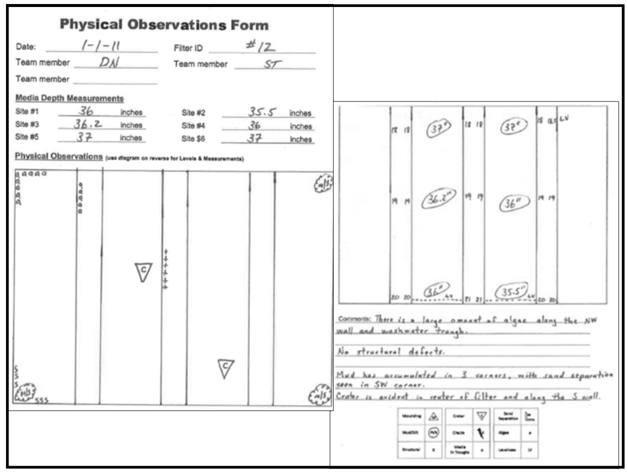


Figure 39: Surface Accumulations: These really aren't cracks... It's dried floc on top of a filter that was drained before backwashing



Physical Observations Form

Date: 1-1-11 Filter ID #12

Team member DN Team member ST

Team member

Media Depth Measurements

Site #1	36 inches	Site #2	35.5 inches
Site #3	36.2 inches	Site #4	36 inches
Site #5	37 inches	Site #6	37 inches

Physical Observations (use diagram on reverse for Levels & Measurements)

Comments: There is a large amount of algae along the NW wall and washwater trough.

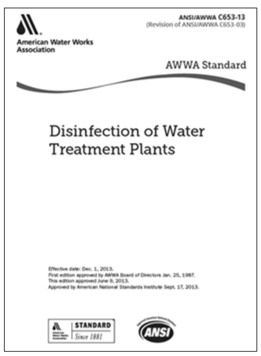
No structural defects.

Mud has accumulated in 3 corners, with sand separation seen in SW corner.

Crater is evident in center of filter and along the S wall.

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



ANSI/AWWA C653-13 (Revision of ANSI/AWWA C653-03)

American Water Works Association

AWWA Standard

Disinfection of Water Treatment Plants

Effective date: Dec. 1, 2013.
First edition approved by AWWA Board of Directors Jan. 25, 1987.
This edition approved June 9, 2013.
Approved by American National Standards Institute Sept. 17, 2013.

STANDARD Since 1881

ANSI

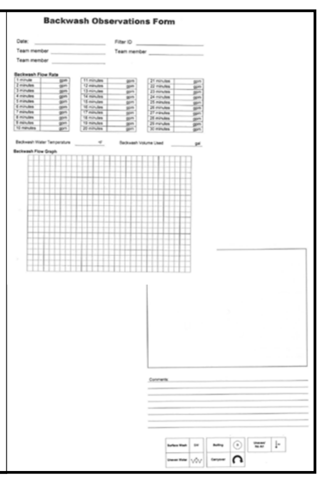
BACKWASH OBSERVATIONS

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

Backwash Water Temperature °F Backwash Volume Used gal

Backwash Flow Graph

Comments:

BACKWASH OBSERVATION - PROCEDURE

Prepare	Prepare backwash observation form
Evaluate	Evaluate secondary wash system • Drop water below top of media; operate surface wash without backwash water • Drop water 4-6 inches below backwash trough; operate air-scour without backwash water flowing
Begin	Begin backwash following plant SOP
Walk around	During backwash, walk around filter looking for signs of problems • Document them on backwash observation form

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

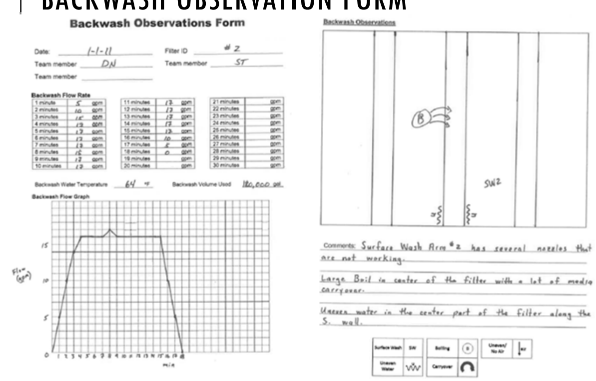
- Backwash trough capacity
  - Troughs able to carry backwash water when working at max capacity
  - 2-inch freeboard inside of trough (TN Design Criteria 4.2.1(f)(3))
  - Make notes in comments sections of backwash observation form
- Note any mechanical system malfunctions

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: DN   Team member: ST
Team member:

Backwash Flow Rate

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

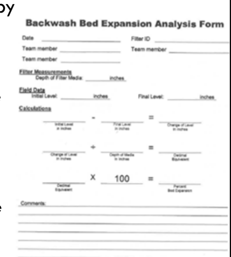
Surface Wash	SW	Boiling	B	Uneven/ No Air	air
Uneven Water		Carryover			

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



RULER GAUGE METHOD (SECCHI DISK)

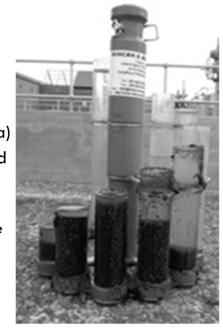
- Before backwashing, lower the ruler gauge into the filter
  - When ruler reaches media surface, record initial reading
- Once backwash begins, lower ruler back into filter to media surface
  - Record final reading
- Calculation

$$L_i - L_f = L_\Delta$$
$$\text{Initial} - \text{final} = \text{change}$$
$$\left(\frac{L_\Delta}{D_{original}}\right) \times 100 = \%\ bed\ expansion$$

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)

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



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

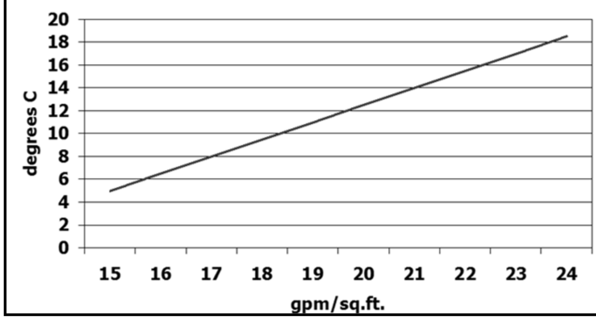
- If rates are not changed during summer and winter months
  - Mudballs may occur during the summer
  - Media loss may occur during the winter
- Colder water temps need lower backwash rates
- Warmer water temps need higher backwash rates

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

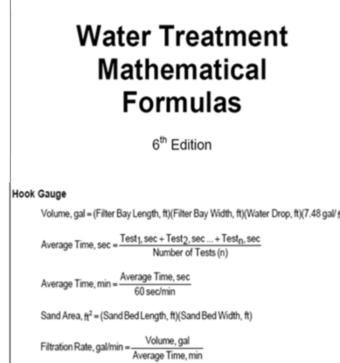
Chapter 9

PROCEDURE

- Step 1. Record length and width of filter on filtration rate form
- Step 2. Secure ruler to filter with a stationary object (not media)
- Step 3. Begin backwash; record metered flow rate
- Step 4. Use stopwatch to time how long it takes water to rise a preset distance: 6 in, 12 in, 18 in, 24 in
- Step 5. Record times on backwash rising rate analysis form

BACKWASH RISING RATE ANALYSIS

Calculations – Formulas from FTC WT Formula Book


Water Treatment Mathematical Formulas

6th Edition

Hook Gauge

Volume, gal = (Filter Bay Length, ft)(Filter Bay Width, ft)(Water Drop, ft)(7.48 gal/ft³)

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

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

Sand Area, ft² = (Sand Bed Length, ft)(Sand Bed Width, ft)

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

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

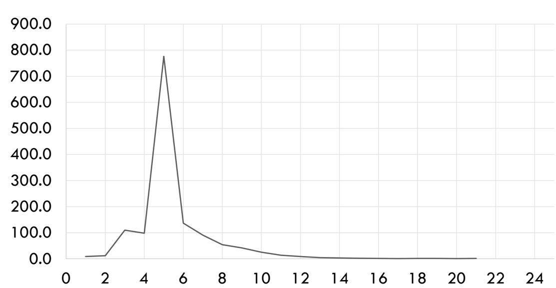
- Backwash turbidity evaluation form
- Stopwatch
- Bucket with rope
- 30 100-mL sample bottles marked in 1-minute increments
- Benchtop turbidimeter

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

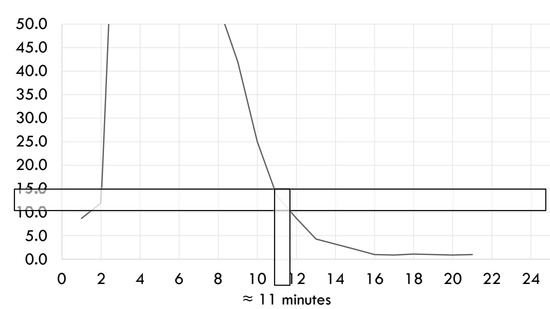
INTERPRETATION OF RESULTS

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

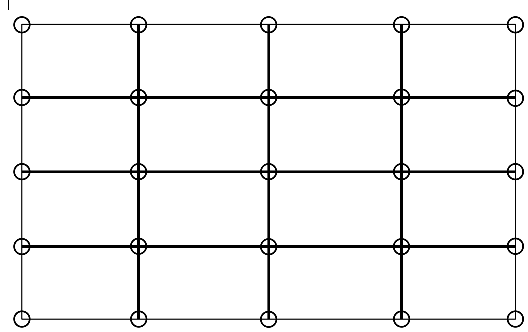
Indicators
- Media boil
- Dead zones
- Excessive mud in filter in one or more areas
- Media separation

DETERMINING THE POINTS OF MEASUREMENT

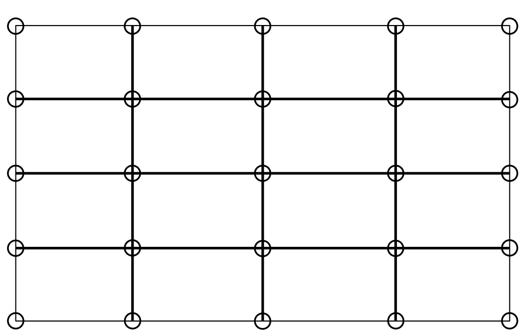
Evaluation
- Top of gravel (footprint) must be measured

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



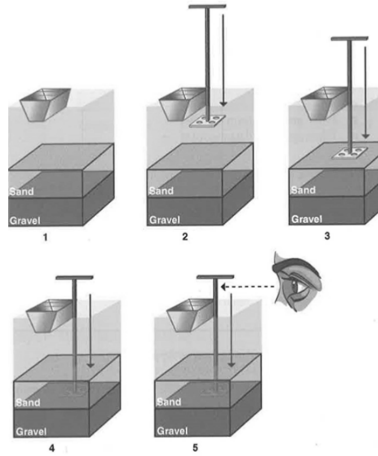
DETERMINING THE POINTS OF MEASUREMENT



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

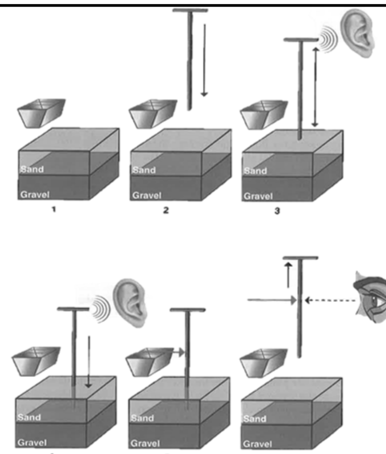
GRAVEL FOOTPRINT ANALYSIS – FLUIDIZED BED METHOD



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 should 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

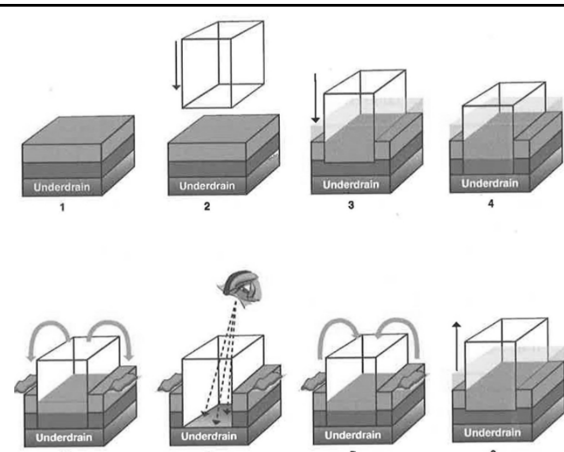
GRAVEL FOOTPRINT ANALYSIS – PUNCH ROD METHOD



TOP OF GRAVEL FOOTPRINT ANALYSIS

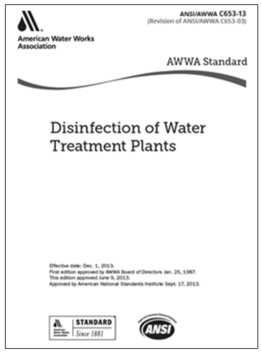
PROCEDURE - METHOD 3: EXCAVATION

- 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


ANSI/AWWA C653-13
(Revision of ANSI/AWWA C653-03)

American Water Works Association

AWWA Standard

Disinfection of Water Treatment Plants

Effective date: Dec. 1, 2013.
First edition approved by AWWA Board of Directors Jan. 25, 1987.
This edition approved June 9, 2013.
Approved by American National Standards Institute Sept. 17, 2013.

STANDARD Since 1881

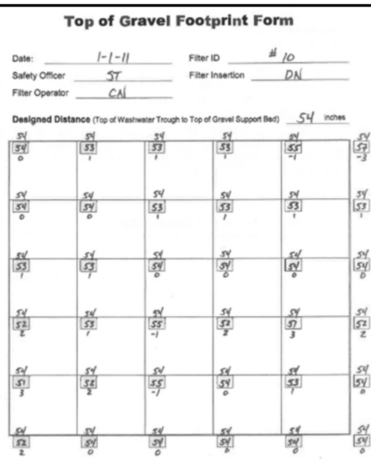
ANSI

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 form 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

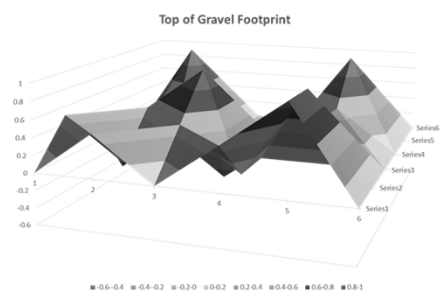

Top of Gravel Footprint Form

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

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

54 / 54 / 0	54 / 53 / 1	54 / 53 / 1	54 / 53 / 1	54 / 55 / -1	54 / 57 / -3
54 / 54 / 0	54 / 54 / 0	54 / 53 / 1	54 / 53 / 1	54 / 53 / 1	54 / 53 / 1
54 / 53 / 1	54 / 53 / 1	54 / 54 / 0	54 / 54 / 0	54 / 54 / 0	54 / 54 / 0
54 / 52 / 2	54 / 53 / 1	54 / 55 / -1	54 / 52 / 2	54 / 51 / 3	54 / 52 / 2
54 / 51 / 3	54 / 52 / 2	54 / 55 / -1	54 / 54 / 0	54 / 53 / 1	54 / 54 / 0
54 / 52 / 2	54 / 54 / 0	54 / 54 / 0	54 / 54 / 0	54 / 54 / 0	54 / 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 ben disrupted leading to filter performance issues
- Any movement greater than +/- ½ inch would indicate possible gravel movement
  - Any movement greater than ¾ - 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

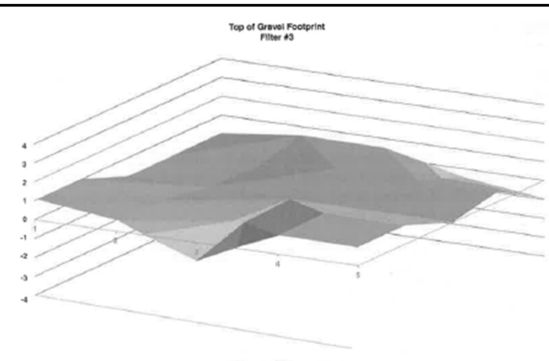
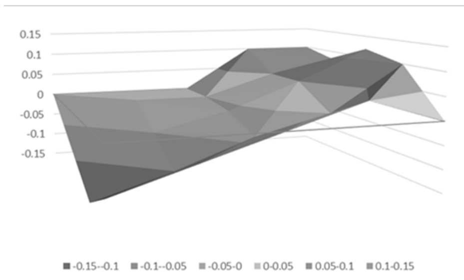
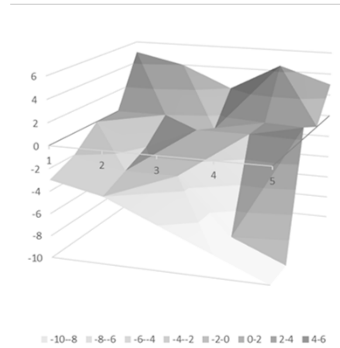


Figure 11-6 When a graph is generated, the filter will not be completely flat. Expect to find a small amount of ripple, but no more than ±1 in. from the designed level.

TOP OF GRAVEL FOOTPRINT



TOP OF GRAVEL FOOTPRINT



Fleming Training Center | TN Department of Environment & Conservation

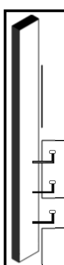
FILTRATION RATE ANALYSIS

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/ft^2 of filter area for turbidity removal plants, and 3 gpm/ft^2 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

HOOK GAUGE METHOD



- **Place** — Place hook gauge in filter & secure to stationary object
  - Top hook should be approximately 2 inches below water surface
- **Filter** — Close filter influent valve while effluent valve stays open
  - Record effluent valve setting and flowmeter reading
- **Watch** — Watch for water level to decline until it reaches the top hook
  - Start stopwatch when water surface reaches top hook
- **Water** — When water surface touches bottom hook (6 inches below top hook), stop timer and record time
  - Perform three times refilling filter each time

RULER GAUGE METHOD

- Secure ruler gauge to filter
- Record beginning water depth obtained from ruler gauge
- Close filter influent valve while leaving effluent valve open
  - Record valve setting and flowmeter reading
- Start stopwatch when water level starts to drop
- After 30 seconds, record new water level

FILTRATION RATE ANALYSIS

Calculations – Formulas from FTC WT Formula Book

Water Treatment Mathematical Formulas

6th Edition

Filtration

Hook Gauge

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

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

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

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

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

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

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)

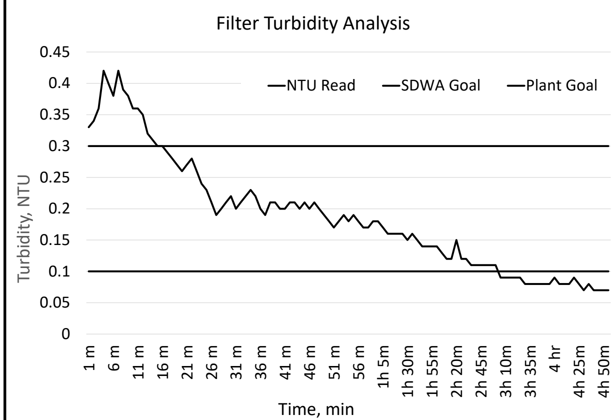
- Collect 100-mL sample every 15 minutes

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



PARTICLE COUNTS TO DETERMINE LOG REMOVAL VALUE (LRV)

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

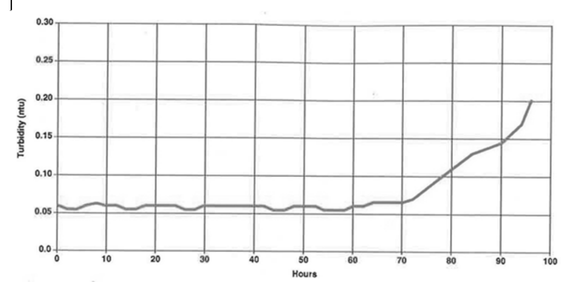
- Graph data and calculate log removal value

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

Where: P_I = # of particles in filter influent

P_E = # of particles in filter effluent

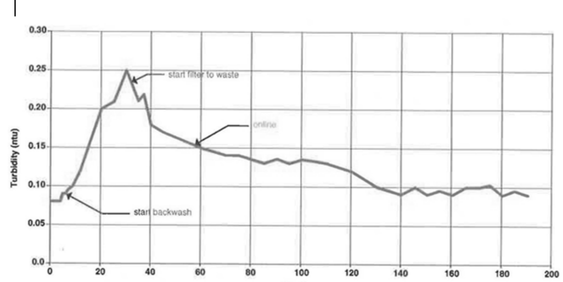
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-5 Excessive filter run time

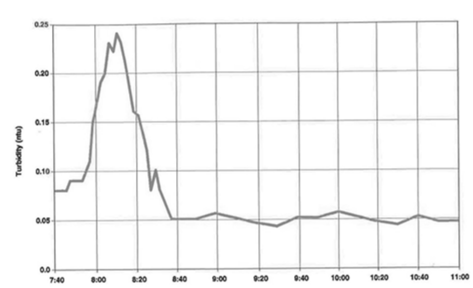
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-6 Excessive ripening time

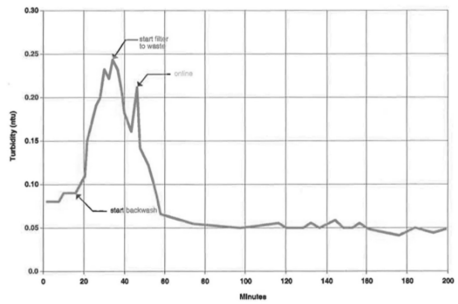
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-7 Typical filter ripening

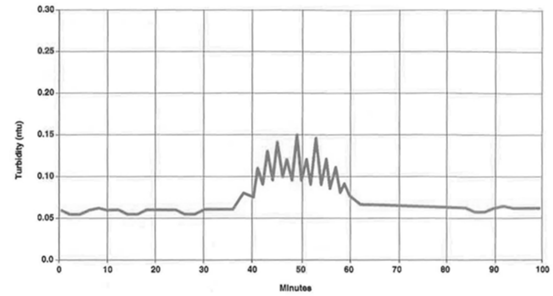
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

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

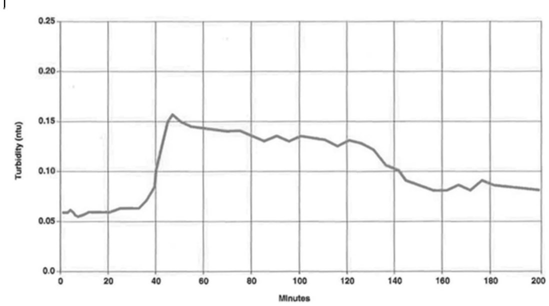
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-9 Hydraulic surging

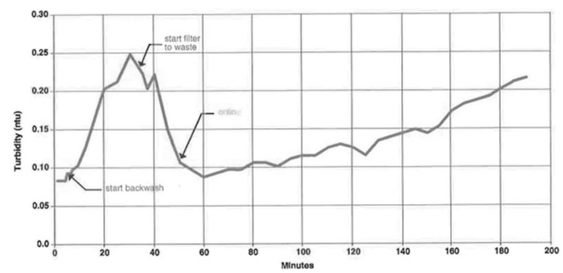
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-10 Step changes

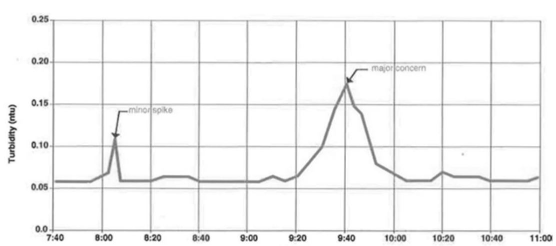
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-11 Rapidly deteriorating filter quality

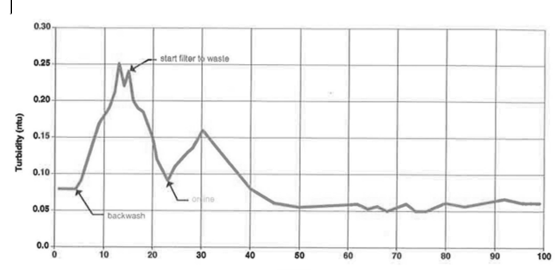
INTERPRETATION OF RESULTS



Source: Pennsylvania Department of Environmental Protection

Figure 13-12 Spikes

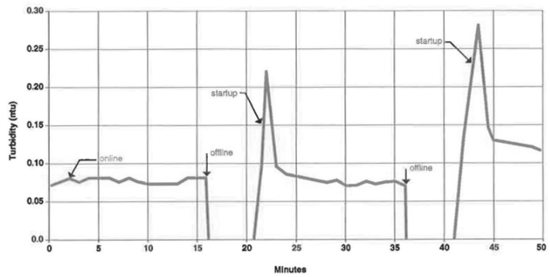
INTERPRETATION OF RESULTS



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

MUDBALL ANALYSIS

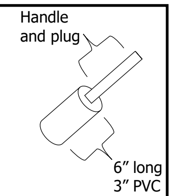
Chapter 14

MUDBALL ANALYSIS

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

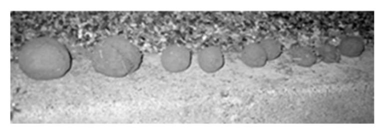
- Particles break into smaller sticky pieces which form spherical shapes and adhere to the sand around them
- Usually range from 1-2 inches or larger
- During formation, mudballs can be found on the media surface
- As they grow, the mudballs will sink deeper into the filter media typically settling along 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



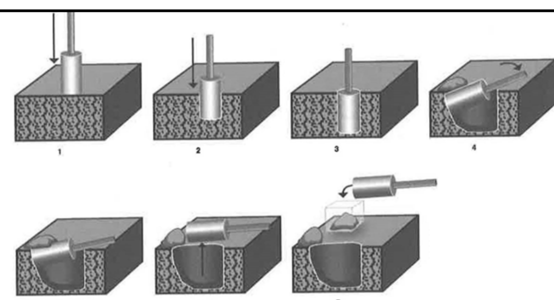
DETERMINING POINTS OF SAMPLE COLLECTION

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

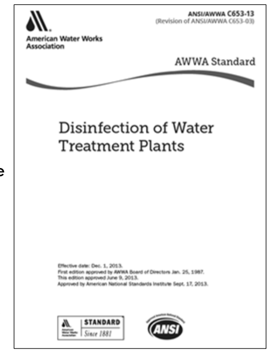
SAMPLE PREPARATION

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

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

- 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

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CARBONATE PRECIPITATION ANALYSIS

Chapter 15

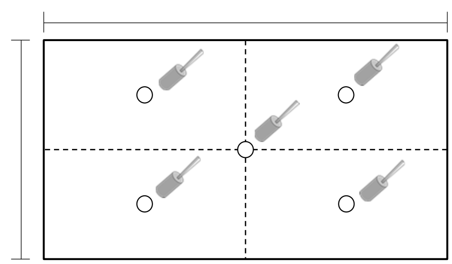
CARBONATE PRECIPITATION ANALYSIS

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 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"

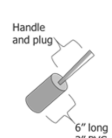
SAMPLING POINTS

Sampling point should be representative of the filter

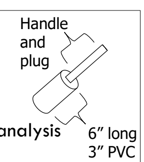


EQUIPMENT NEEDED

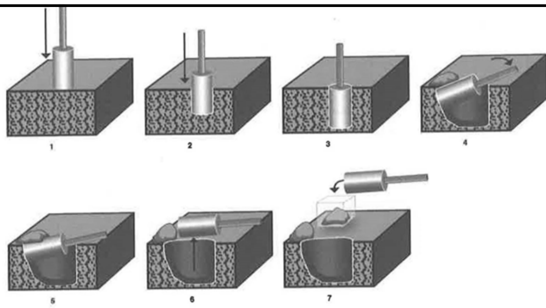
- Carbonate precipitation analysis form
- Balance
- Large crucibles
- 100-mL graduate cylinder
- Water squeeze bottle
- Two 2-L beakers
- Small coring device
- 1-gal plastic bag
- 4-L bucket
- Weighing boats



SAMPLE COLLECTION



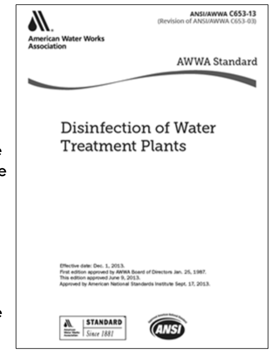
- Can use media left in 4-L bucket from mudball analysis
  OR
- Backwash filter
- Drain water to below media surface
- Beginning with the first sampling point, push the mudball sampler 6 inches into the media
- Tilt the mudball sampler back until it is horizontal with the filter bed
- Lift the mudball sampler, keeping it horizontal
- Empty into a baggie
- Repeat this steps for remaining sampling spots, placing all samples into same bag



SAMPLE COLLECTION

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

1. Place entire sample in 4-L bucket →
2. Wash sample with water until free of any mud/silt →
3. Place sample into drying crucibles →
4. Dry entire sample 24 hours at 105°C
   - Leave sample in oven until ready for next procedure

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

- Goggles
- Gloves
- Apron
- Fume hood
- 2-L of 50% HCl
- Distilled water in squirt bottle

ACID WASH PROCEDURE

Weight Sample

- Pour 50 mL of the 50% HCl into the 2-L beakers
- Slowly sift weighed sample into beaker
  - 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

- 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

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

- Percentage of Carbonate

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

- Volume of Carbonate

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

- Percentage of Carbonate

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

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

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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

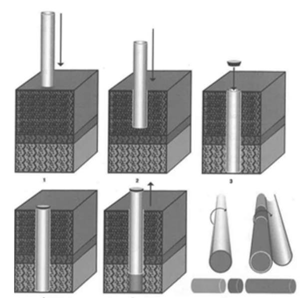
EQUIPMENT NEEDED CONT'D

- 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

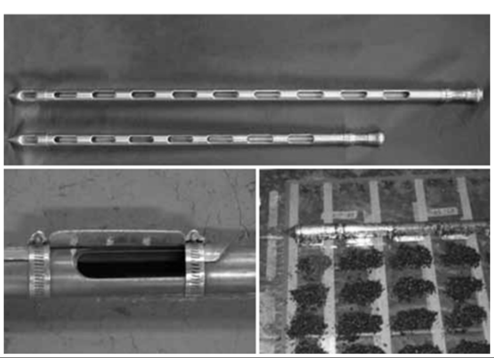
SAMPLE COLLECTION

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

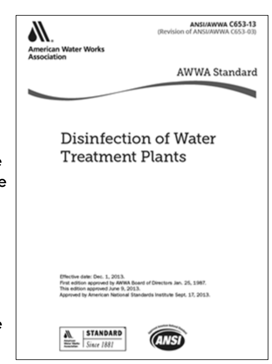


CORING DEVICE



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


ANSI/AWWA C653-13
(Revision of ANSI/AWWA C653-03)

American Water Works Association

AWWA Standard

Disinfection of Water Treatment Plants

SAMPLE PREPARATION

Step 1.	Step 2.	Step 3.	Step 4.
Place entire sample in 4-L bucket	Gently wash entire sample with water until free of mud and silt	Place sample in drying crucibles	Dry entire sample in drying oven for 24 hours at 105°C

SIEVE TESTING

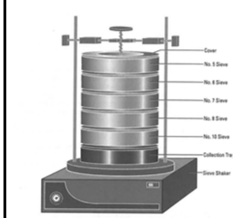


Figure 18-4 Arrangement of first set of sieves

- **Step 1.** Weigh first set of sieves (No. 5-10) & record weight of each under the Initial Sieve Weight
- **Step 2.** Arrange first set of sieves on sieve shaker
  Top to bottom: No. 5, 6, 7, 8, 10, & collection tray
- **Step 3.** Remove dried sample from oven and allow to cool in desiccator
- **Step 4.** Weigh 150 g of media and record as your sample weight; place remaining media back in oven

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

SIEVE TESTING

- **Step 13.** Place the media deposited in collection tray in clean container; keep for later (container #1)
- **Step 14.** Carefully weigh each sieve with media on it with balance and record under Final Sieve Weight
- **Step 15.** Place weighed media container #2
- **Step 16.** Weigh final set of sieves (No. 25-45) and record as initial sieve weight
- **Step 17.** Arrange the final set of sieves on shaker in order

SIEVE TESTING

- **Step 18.** Place media from collection tray (container #1) in top of new series of sieves
- **Step 19.** Secure top & begin shaking sample at a shaker setting of 50%
- **Step 20.** Place media deposited in collection tray in clean container (#1)
- **Step 21.** Weigh each sieve with media on it with balance and record under Final Sieve Weight
- **Step 22.** Once media is weighed, place in container #2
- **Step 23.** Perform calculations

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

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

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**		

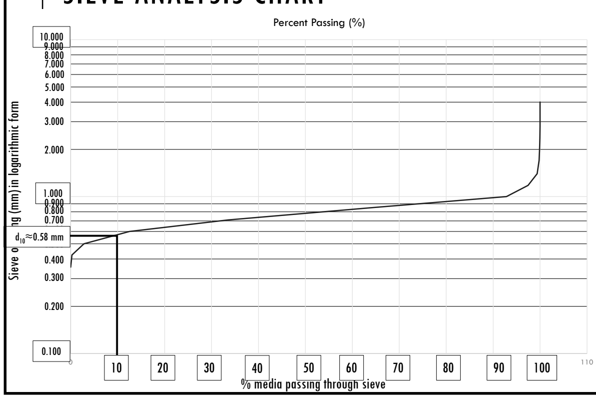
CALCULATIONS

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 last somewhere in the testing procedure and results may not be accurate

SIEVE ANALYSIS CHART



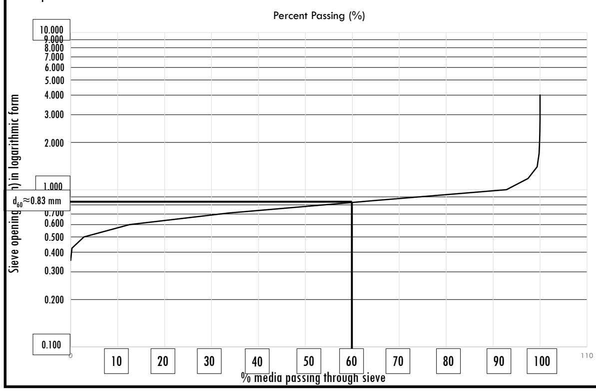
DETERMINING d_{10}

- 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

SIEVE ANALYSIS CHART



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 mm
d_{60} = 0.83 mm

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

$$UC = 1.43$$

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

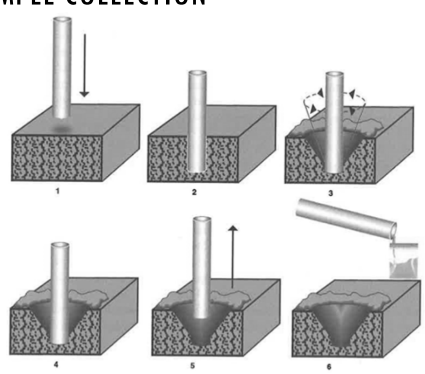
Equipment

- 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

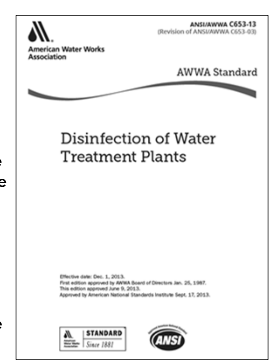
Step 1.	Select 3 sampling points in filter
Step 2.	At end of filter run, drain all water from media
Step 3.	Enter filter; standing on plywood, collect first sample
Step 4.	Gently push core sampler into media to 2-inch mark
Step 5.	Plug end of coring device; slowly retract sampler from media
Step 6.	Deposit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

SAMPLE COLLECTION CONT'D

Step 7.	Repeat steps 4-6 each bag depth
Step 8.	Repeat steps 4-7 at second and third sampling sites (all three sample sites will go into one bag for each depth)
Step 9.	Once composite samples for all 3 sample sites are collected, backwash the filter and drain the media
Step 10.	Repeat steps 3-8 placing media samples in bags labeled After Backwash

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

Step 1.	In lab, separate before and after bags
Step 2.	Thoroughly mix each sample by shaking bag vigorously
Step 3.	Use 100-mL graduated cylinder to measure 50-mL of sample from “0-2 in: Before Backwash” bag
Step 4.	Transfer this 50-mL sample to 500-mL flask
Step 5.	Add 100 mL tap water to sample; shake vigorously for 60 seconds
Step 6.	Place this turbid water in the 500-mL beaker

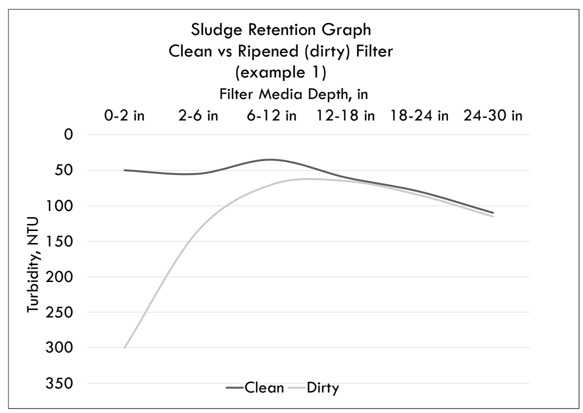
SAMPLE PREPARATION

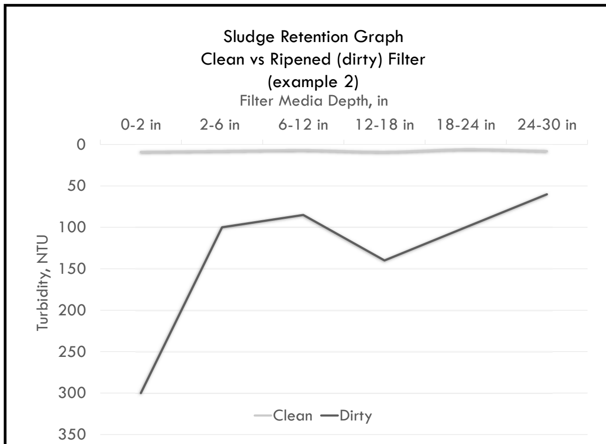
Step 7.	Using same media, repeat steps 4-6 four more times (until a total of 500 mL of turbid water collected
Step 8	Stir 500-mL sample; perform turbidity analysis
Step 9.	Multiply value obtained by 2
Step 10.	Record in the “0-2 in: Before Backwash” box on sludge retention profile evaluation form
Step 11.	Repeat steps 2-10 for remaining samples
Step 12.	Graph turbidity (x-axis) vs media depth (y-axis) for before and for after backwash samples

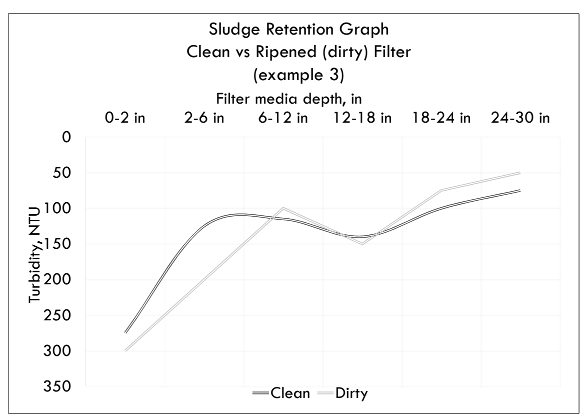
INTERPRETATION OF RESULTS

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

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UNDERDRAIN INSPECTION

Chapter 18

UNDERDRAIN INSPECTION

Types and variations

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

UNDERDRAIN SYSTEMS

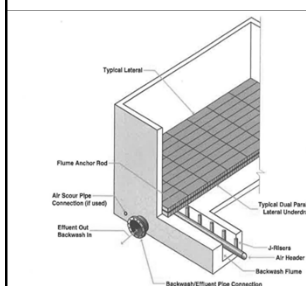


Figure 18-2 Typical dual parallel lateral filter arrangement

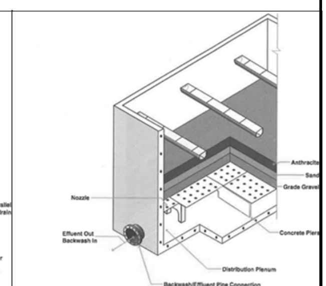


Figure 18-3 Typical false floor nozzle filter arrangement

UNDERDRAIN SYSTEMS

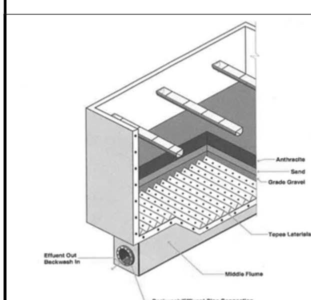


Figure 18-4 Typical folded plate lateral filter arrangement

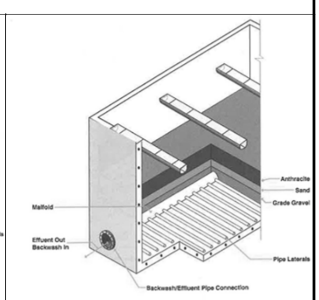


Figure 18-5 Typical pipe lateral filter arrangement

UNDERDRAIN SYSTEMS

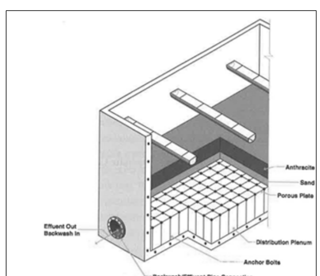


Figure 18-6 Typical porous plate filter arrangement

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

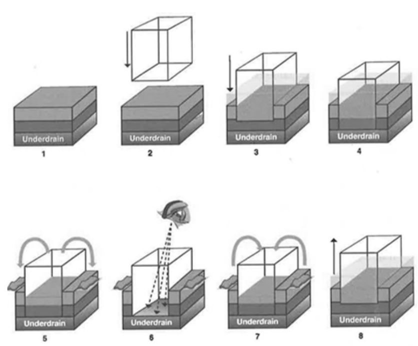
Step 3. Open backwash valve slightly to fluidize bed

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

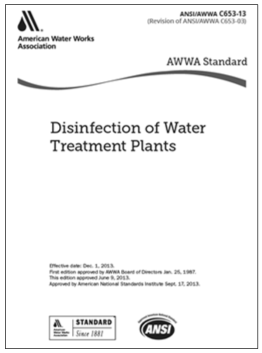
- Cracks in underdrain block or nozzles
- Holes in underdrain or floor
- Clogged underdrain block or nozzle inlets
  - Note type of material clogging inlet
- Grout failure
- Broken nozzles
- Structural failures

PROCEDURE

Step 8.	Note all deficiencies on underdrain inspection form
Step 9.	After inspection, replace media in proper order
Step 10.	Fluidize media and remove excavation box (see diagram from pg. 192)

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


ANSI/AWWA C653-13
(Revision of ANSI/AWWA C653-03)

American Water Works Association

AWWA Standard

Disinfection of Water Treatment Plants

Effective date: Dec. 1, 2013.
First edition approved by AWWA Board of Directors Jan. 25, 1987.
This edition approved June 9, 2013.
Approved by American National Standards Institute Sept. 17, 2013.

STANDARD
Since 1881

ANSI

INTERPRETATION OF RESULTS

- Clogs should be removed, preferably chemically
- Replace broken nozzles, if applicable
- Random evaluation can be problematic
- Excavate <u>all</u> 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

Membrane Treatment Processes

California State University, Sacramento

Objectives

- Introduction
- Treatment Technologies
- Operations
- Operational Issues
- Integrity Testing
- Process Residuals
- Electrodialysis

2

Introduction to Membrane Filtration

3

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

4

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

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Flux

- A flow or flowing
- Term used to describe the rate of water flow through the semipermeable membrane
- Expressed in gal/day/ft^2 of membrane surface area or gram/second/cm^2
- 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

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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

7

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

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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

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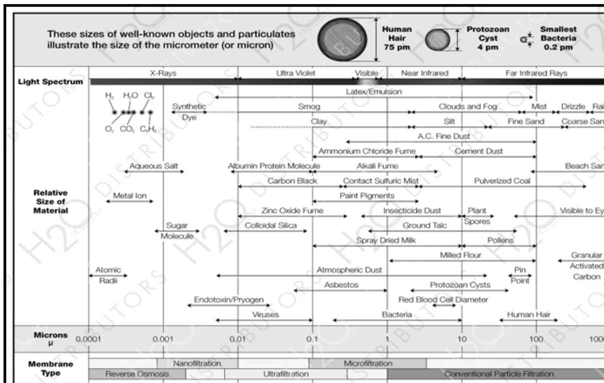

Source: "Water Proccessing: Third Edition", Wes McGowan, Water Quality Association, 2001

TYPICAL REMOVAL RATES FOR THIN-FILM COMPOSITE MEMBRANES
At 65 PSI Feed Pressure and 77° Temperature

Arsenic	94%	Barium	99%	Flouride	93%	Nitrates	87%	Nitrites	87%
Asbestos	99%	Cadmium	98%	Lead	99%	Radium	80%	Hexavalent Chromium	86%
Cyanide	86%	Copper	99%	Mercury	91%	Selenium	96%	Trivalent Chromium	88%

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

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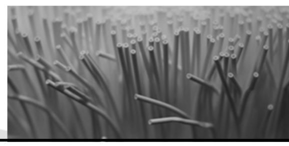
Membrane Filtration Units

- 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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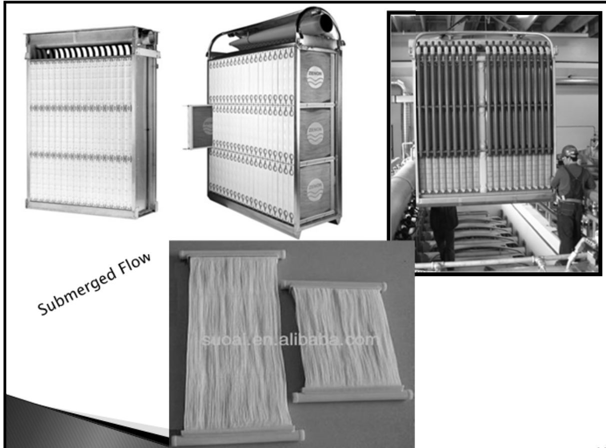

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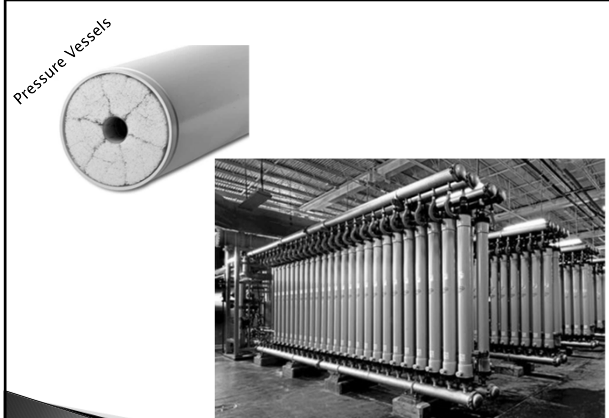

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Membranes

- Spiral wound
- Hollow fine fiber
- Tubular

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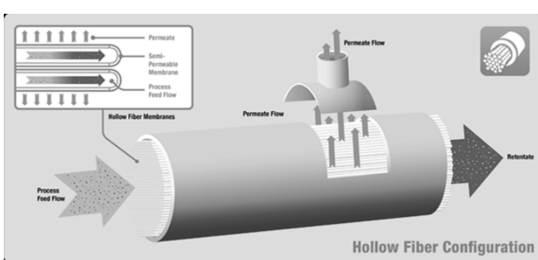
Hollow Fiber Membrane



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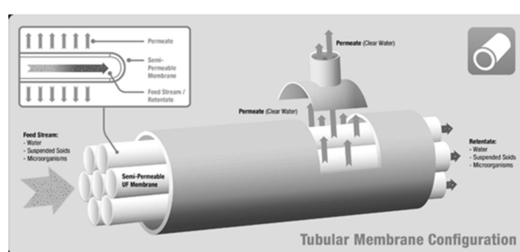
Tubular Membrane



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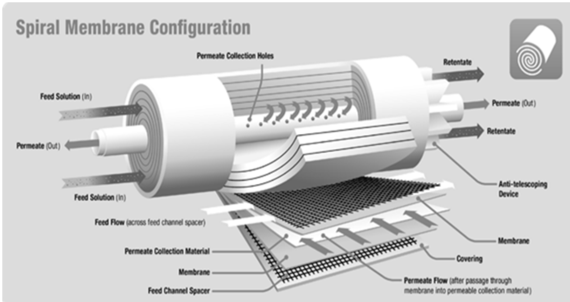
Spiral Wound Membrane



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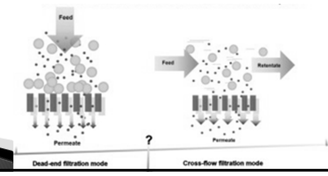
Membrane Flow Types

- 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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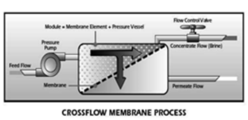
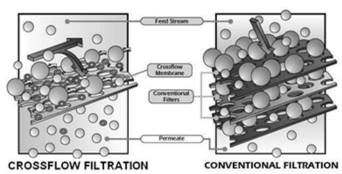
Crossflow Filtration

- 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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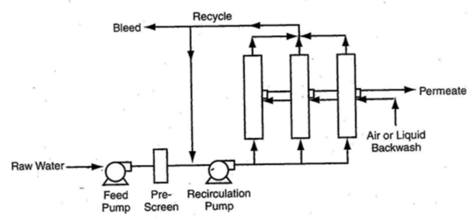
System Configurations



Pressure driven system configuration with crossflow

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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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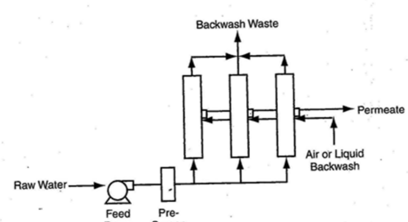
System Configuration



Pressure driven direct flow

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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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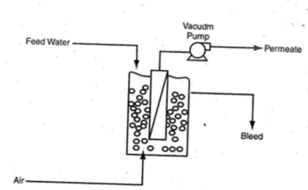
System Configuration



Direct flow submersible

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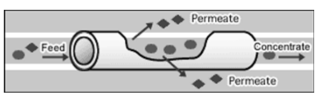
Inside-Out Filtration



- 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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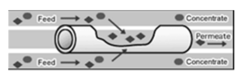
Outside-In Filtration



- 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	Conventional Filtration
Treatment is independent of pre-treatment conditions and raw water turbidity	Requires optimized chemical pretreatment (coagulation, flocculation, sedimentation)
Pore size in membranes forms an effective barrier to cyst sized particles	Operators must adjust treatment for changing water conditions
No need for a filter to waste step at the beginning of a filtration run	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	Conventional 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.	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 productivity, quality of the filtrate remains the same.	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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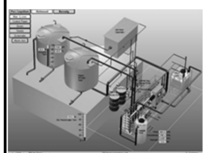
Operations



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

37

RO 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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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 35-40ºC 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	• Mechanical failure inside unit • Belt failure • Oil pump leak	• Rebuild failed compressor • Replace belt • Repair leak • Use portable air compressor
Raw water pump station failure	• Electronic failure of the uninterrupted power supply (UPS)	• Bypass UPS • Conduct routine monthly checks of all plant UPS units
Computer lockup	• Central SCADA computer failure	• 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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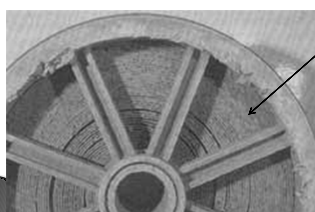
Inorganic Fouling

- 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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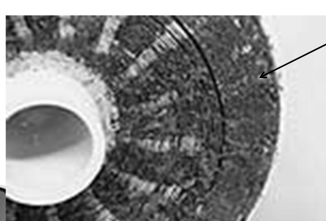
Biofouling

- 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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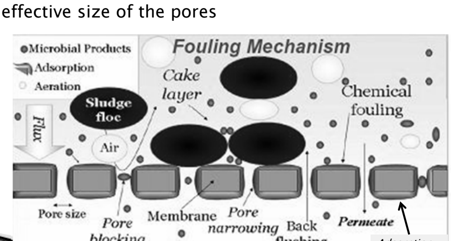
Fouling

- 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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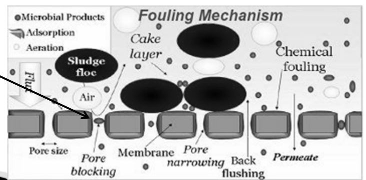
Fouling

- **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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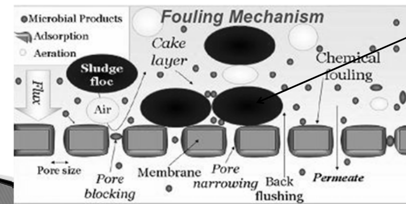
Fouling

- **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.

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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.

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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

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

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

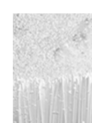
Air Pressure Decay Testing

- 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

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

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

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

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Process Residuals of Membrane Filtration

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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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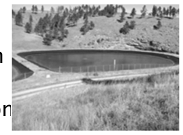
Process Residuals

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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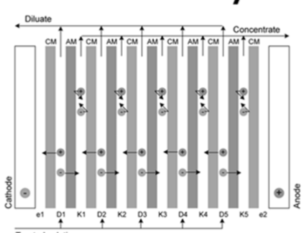
Electrodialysis



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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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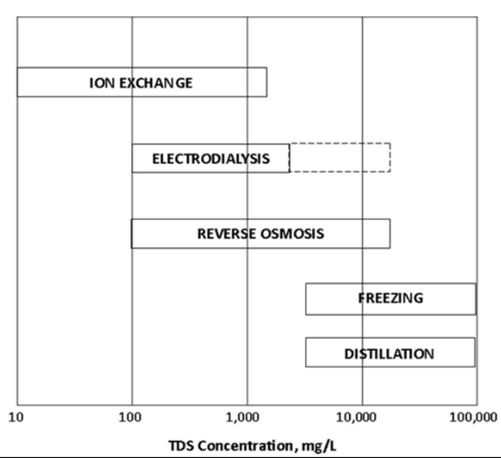

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Electrodialysis (ED)

- 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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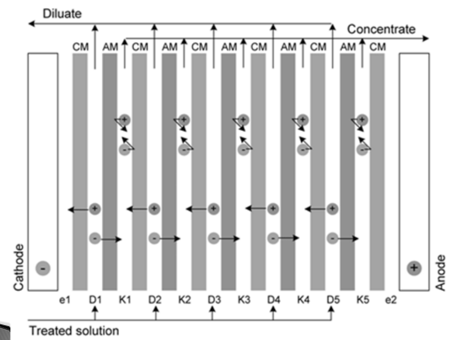
Electrodialysis (ED)



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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 110ºF
  - 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

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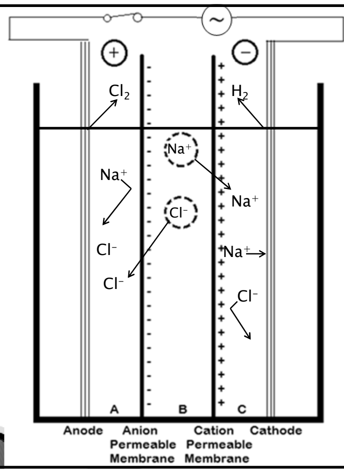

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Process

- 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

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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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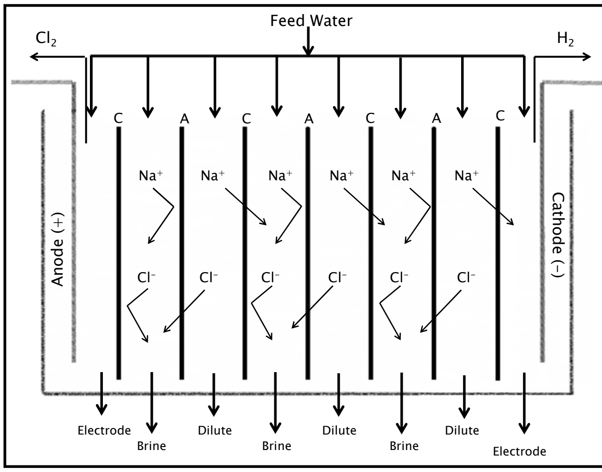

Multicompartment Unit

- 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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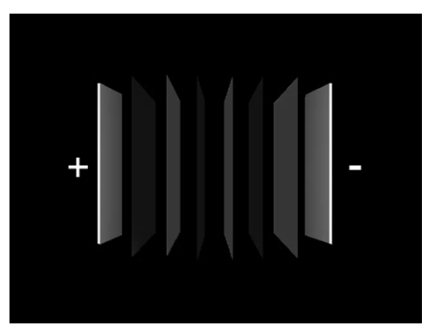

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Parts of an ED Unit

- 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 <u>any</u> 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

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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

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

_____ 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

1

PUMPS

California State University: Sacramento

2

Objectives

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

3

CLASSIFICATION OF PUMPS

4

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

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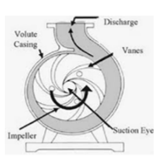
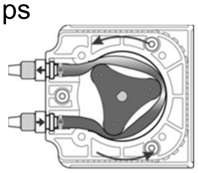
Types of Pumps

- Velocity Pumps



- Positive-Displacement Pumps



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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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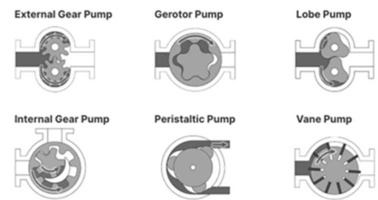
POSITIVE DISPLACEMENT PUMPS

8

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: piston, diaphragm, gear, or screw pump



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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

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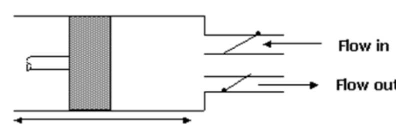
Reciprocating Pump

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



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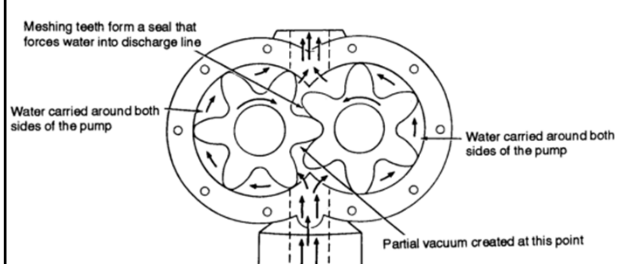
Rotary Pumps

- Uses lobes or gears to move liquid through pump



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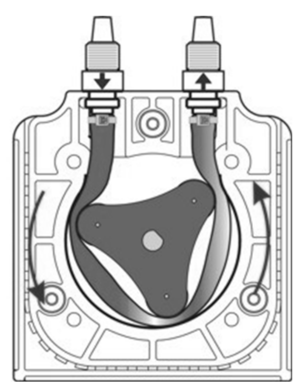
Peristaltic Pumps

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



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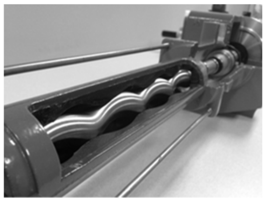
Screw Pumps

Incline screw pumps handle large solids without plugging

- 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



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VELOCITY PUMPS

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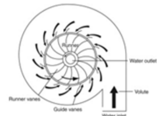
Velocity Pumps

- 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



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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

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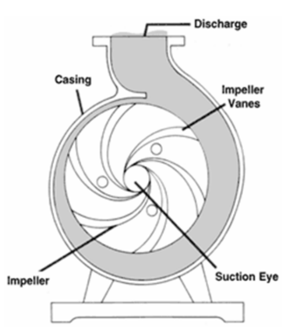
Velocity Pump Design Characteristics

- 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



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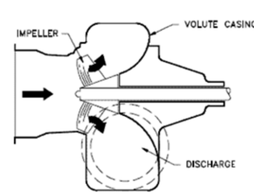
Velocity Pump Design Characteristics

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



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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

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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

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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

Single Volute

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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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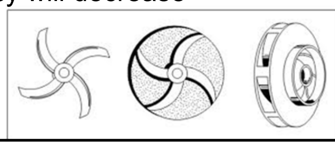
Let's Build a Centrifugal Pump

- 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.

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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

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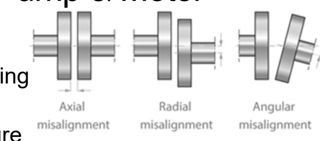
Misalignment of Pump & Motor



- 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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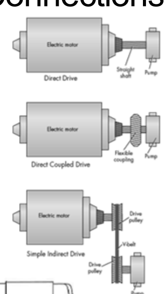
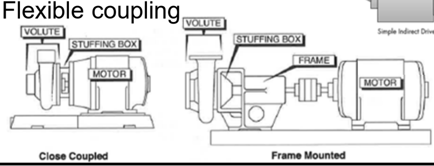
Common Pump & Motor Connections

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





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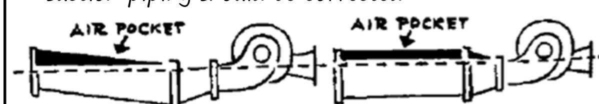
Let's Build a Centrifugal Pump

- 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



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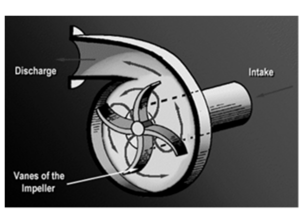
Let's Build a Centrifugal Pump

- 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.

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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

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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

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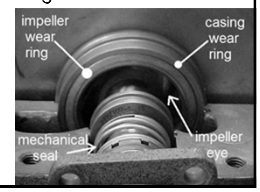
Let's Build a Centrifugal Pump

- 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.



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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.

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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

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Stuffing Box

#9 – Packing should be replace 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.

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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 form being drawn or sucked into the pump and/or the water being pumped from coming out

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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
  - 180º if only 2 rings are in stuffing box
  - 120º for 3 rings
  - 90º if 4 rings or more are in set

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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

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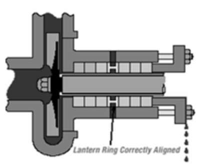
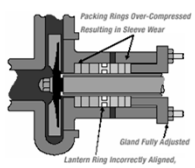
Lantern Rings (aka Seal Cage)

- 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





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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.

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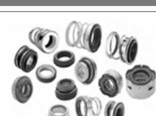
Mechanical Seals



- 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 160ºF (71ºC)
- 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.

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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

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Packing vs. Mechanical Seals

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

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Packing Rings vs. Mechanical Seal

- Advantages
  - Less expensive, short term
  - Can accommodate some looseness
- Disadvantages
  - Increased wear on shaft or shaft sleeve
  - Increased labor required for adjustment and replacement

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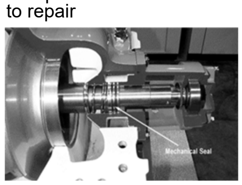
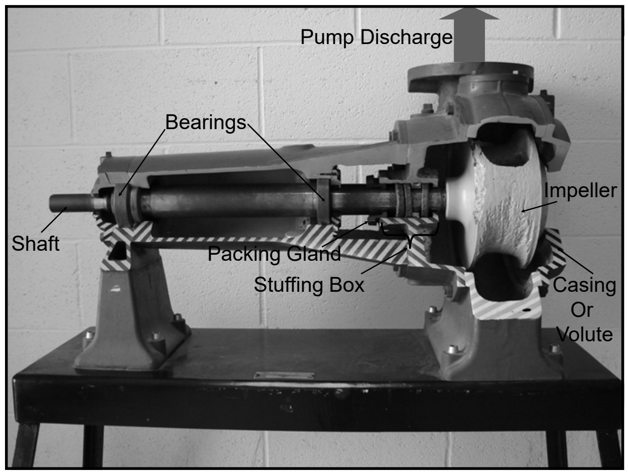
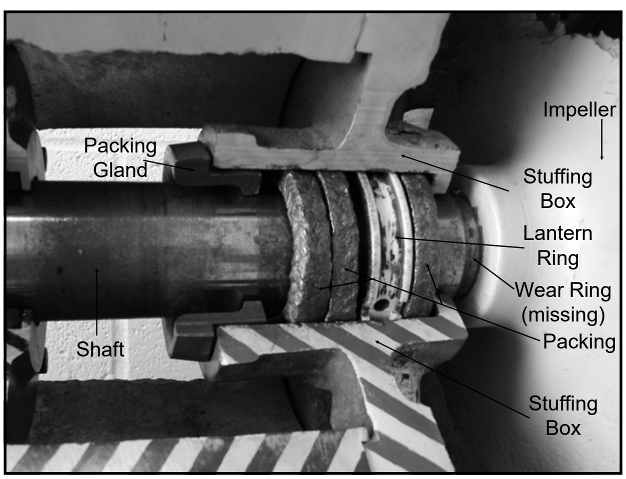
Mechanical Seal vs. Packing Rings

- 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

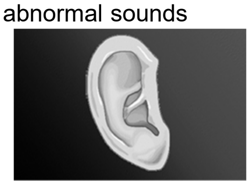
- Pump and motor should be tested and complete test results recorded as a baseline for the measurement of performance within the first 30 days of operation

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



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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

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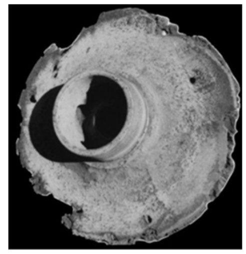
Monitoring Operational Variables



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

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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

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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

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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)

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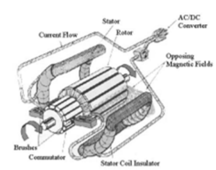
Pump Won't Start?



- 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 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 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 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 snuggly 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.

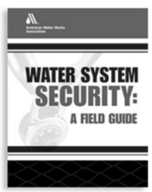
37. gasoline, propane, methane, natural gas and diesel oil (diesel fuel)
38. make, model, capacity, type, date and location installed, and other information for both the driver (motor) and the driven unit (pump)
39. Make sure the power to the device is disconnected. This is critical since rubber gloves,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

Section 7

Water System Security

WATER SYSTEM SECURITY

A Field Guide



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EMERGENCY PLAN

- Goal:
  - Assign roles and responsibilities to specific individuals and groups within the organization
  - Provide guidelines for conducting appropriate response actions
  - Establish systems that can mitigate the effect of an emergency or critical incident, prevent it from escalating, and enhance the recovery process

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PLANNING

- Three main levels of planning
  - Strategic
    - Comprehensive
    - Long term
    - Generalized
  - Operational
    - Focused
    - Short term
  - Tactical
    - Specific objective
    - Narrow goals

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HOW TO PLAN

- Follow steps
  - Assess the current conditions
  - Determine goals and objectives
  - Allocate appropriate resources
  - Implement the plan
  - Assess the plan and modify, if needed

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EMERGENCY RESPONSE PLAN

- Improves understanding and cooperation within a utility and with external emergency responders
- Produces higher level of coordination
- Allows critical resources to be applied better
- Produces a physical document detailing emergency response capabilities and responsibilities
- Should be an ever changing document

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VULNERABILITY ASSESSMENT

- A process in which the effects of an unforeseen event are evaluated.
- Should include all aspects of the entire system
  - Physical
  - Operational
  - Critical mission

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VULNERABILITY ASSESSMENT

- Four step process
  - Identify and describe major components of the total water supply system
  - Identify threats and estimate potential effects of those threats on the each component of the system
  - Establish performance goals and acceptable levels of service for the system
  - If determined that system will fail to operate at desired levels, identify
    - Key or critical system components
    - Appropriate corrective measures

IDENTIFY MAJOR SYSTEM COMPONENTS

- Administration and operations
- Source water
- Transmission system
- Finished water storage
- Distribution system
- Supporting infrastructure
  - Electric power, transportation, communications

IDENTIFY MAJOR SYSTEM COMPONENTS

- Be as detailed as possible
  - Maps and blue prints
  - Geographic information system (GIS)
  - Hydraulic models
  - General description for distribution system
    - Pressure zones
    - Location of pressure relief valves
    - Pipe sizes
    - Pipe material and ages
    - Typical distance between hydrants
    - Major valve locations

IDENTIFY THREATS, ESTIMATE POTENTIAL EFFECTS

- Accident
- System malfunction
- Vandalism
- Human error
- System aging
- Natural disaster
- Extortion
- Sabotage
- Waste leakage/seepage
- Terrorism
- Civil unrest

IDENTIFY THREATS, ESTIMATE POTENTIAL EFFECTS

- This step should include
  - Variety of utility staff
    - Engineering, operations, and maintenance personnel
  - Local law enforcement staff
    - Different and fresh perspective
    - May see something that utility staff overlooked

IDENTIFY THREATS, ESTIMATE POTENTIAL EFFECTS

- Critical components of system
- Most likely components to be threatened
- Level of threat

IDENTIFY THREATS, ESTIMATE POTENTIAL EFFECTS

- Individual
  - Vandal
    - Has a goal in mind, but not necessarily a target
    - Crime is one of opportunity
  - Lone wolf
    - An individual working independently
    - Target is clearly defined
  - Insider
    - Present or former employees and contractors

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IDENTIFY THREATS, ESTIMATE POTENTIAL EFFECTS

- Groups
  - Domestic extremist groups
  - Terrorist organizations

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ESTABLISH PERFORMANCE GOALS & ACCEPTABLE SERVICE LEVELS

- What is the mission of a water utility?
- Is it to provide safe, clean drinking water at all times?
- What about water for fire protection or sanitary purposes?
- If a disaster strikes, can the utility provide an adequate supply of water to fight fires?
- Who are the priority customers that may need uninterrupted service?

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IDENTIFY CRITICAL SYSTEM COMPONENTS AND SYSTEM VULNERABILITY

- Critical Components
  - Components whose failure will most affect the delivery of safe and adequate drinking water
  - Most vulnerable to failure or partial failure due to an intentional act or natural disaster
  - Failure will reduce system's ability to meet minimum requirements

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IDENTIFY CRITICAL SYSTEM COMPONENTS AND SYSTEM VULNERABILITY

- Critical Components
  - Personnel
    - Most critical component
  - Operational considerations
    - Planning, operations, maintenance, security procedures and activities
  - Physical facilities
    - Source water reservoir, pipelines, pumps, treatment facilities, buildings, tanks and vehicles
  - Biological and chemical processes
    - Generate or threaten the production and delivery of safe water
  - Cyber, supervisory control and data acquisition (SCADA), and communications
    - Sensors, computers, internet, intranet, telecommunications, telemetry, and computer based communications

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PERSONNEL

- Subject to wide range threats
  - Physical
  - Biological
  - Chemical
  - Psychological threats

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OPERATIONAL CONSIDERATIONS

- The "how" you do things must be considered when evaluating critical components, threats, and mitigating measures
  - Operational aspects
  - Routine and scheduled inspections
  - Who performs what functions
  - Passive or active security measures

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PHYSICAL FACILITIES

- "Things" we see and work with on a daily basis
  - Source water
  - Pumps
  - Tanks
  - Distribution lines
  - Etc.

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CHEMICAL, BIOLOGICAL, and RADIOLOGICAL CONCERNS

- Dangerous contaminants could be added to the water supply at any point
  - From source to distribution system
  - Released in a facility
- Destruction of chemicals that are used by utility to treat drinking water
- Contamination of treatment chemical

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CYBER, SCADA, and COMMUNICATION ISSUES

- SCADA or other data systems are vulnerable
  - Many equipped with "back doors" to allow access by system administrators
  - Connected to email which can carry viruses
- AMR (automatic meter readers)
  - How would the utility bring in revenue

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PROTECTING SENSITIVE INFORMATION

- In the wrong hands, a vulnerability assessment could be very dangerous
- Freedom of Information Act (FOIA)
  - Law that gives you the right to access information from the federal government.
  - If federal agency obtained assessment, it could become public record
- Vulnerability assessments may not be protected under state or local "open record" or "sunshine" laws or codes.
  - Could be available for the public to view

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PROTECTING SENSITIVE INFORMATION

- Have utility/city attorney do some background work
  - Study state and local FOIA-type laws and codes to determine what the utility would have to reveal after conducting a vulnerability assessment
  - Before drawing up a request for proposal of vulnerability assessment, determine if the assessment could be written to fit under any exemptions provided in state or local laws

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PROTECTING SENSITIVE INFORMATION

- If sensitive information is requested, utilities should require:
  - Identification of organization or persons requesting information
  - Exactly what information they wish to review
  - What purpose they seek that information
- Utility attorney should review request before releasing any information

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INTERDEPENDENCIES

- A utility relies on other utilities and services
  - Electric power
  - Natural gas
  - Diesel or propane fuel
  - Sanitary sewer system
  - Telecommunications
  - Transportation system
  - Emergency responders

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MITIGATION MEASURES

- Define safeguards or mitigation measures that can protect assets
- Things to consider during mitigation
  - Fiscal resources
  - Staff resources
  - Political considerations
  - Social and cultural considerations
  - Legal and regulatory considerations

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MITIGATION MEASURES PERSONNEL

- Establish a “culture of security”
  - Incorporate security in every aspect of the utility and its mission
  - Include security in the daily routine
  - Identify it as key organizational value
  - Appoint a security manager responsible for addressing security needs at the utility

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MITIGATION MEASURES PERSONNEL

- Develop written security policies and procedures
- Incorporate these policies and procedures into the general emergency preparedness plan
- Make sure all crucial roles and responsibilities are assigned to appropriate personnel
  - Employees, contract service providers, or emergency service providers

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MITIGATION MEASURES PERSONNEL

- Policies and procedures to consider
  - Make it a rule that all doors are locked and alarms set at your office, well houses, treatment plants, and vaults
  - Tell your employees to question strangers in your facilities, and do not allow access to anyone who does not have a valid reason for being there
  - Indicate restricted areas by posting “Employees Only” signs
  - Do not leave keys in equipment or vehicles at any time

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MITIGATION MEASURES PERSONNEL

- Train the people who must implement these procedures
- Conduct background checks on employees
  - Initially and periodically
- Control entry to the plant
  - Keys, ID badges, etc.

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MITIGATION MEASURES OPERATIONAL

- Source Water Treatment
  - Must be able to get raw, untreated water during emergencies.
  - Establish connections with nearby utilities
- Distribution System
  - Tamper proof hydrants and valve boxes
  - Fence around vulnerable areas with lock
  - Early warning systems to notify operator of changes in chemical characteristics, flows, pressures, and temperature
  - Establish emergency notification protocol with the sanitation system
    - This needs to go both ways

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MITIGATION MEASURES OPERATIONAL

- Operations
  - Educate employees
    - Instruct them to report unusual situations
    - Cross train them to provide back up capabilities during emergencies
  - Develop agreements with neighboring utilities
  - Control public access to critical information about the utility
  - Vary the scheduling of operational procedures
  - Establish a protocol for determining at what point you take action, notify law enforcement, notify the public and/or shut down the system

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MITIGATION MEASURES VISITORS

- Look at policies addressing contractors, visitors, and scheduled tour groups
- Eliminate or limit public access to critical areas of the plant
- Ensure all visitors have proper identification
- Schedule, screen and verify all deliveries to the plant and delivery personnel

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MITIGATION MEASURES PHYSICAL

- Primary objective is to prevent theft and sabotage
- Accomplished by deterring or defeating the adversary
  - Deter – system must be perceived as too difficult to defeat
  - Defeat – requires detection, delay, and response

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MITIGATION MEASURES PHYSICAL

- Detection
  - Discover via a protective force
  - Analyzing must included with this step
  - Exterior and interior detection sensor technologies
    - Microwave
    - Infrared (passive and active)
    - Vibration
    - Video motion detectors
    - Close circuit television systems
    - Proximity

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MITIGATION MEASURES PHYSICAL

- Delay
  - Provide obstacles to increase adversary's task time
  - May be passive or active
  - Obstacles are usually physical barriers
    - Fencing, gates, locks
    - Distance
    - Guard stations
    - Roadway configurations
    - Visual barriers

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MITIGATION MEASURES PHYSICAL

- Response
  - Prevent adversary from accomplishing the intended act
  - Includes
    - Communicating with the response force
    - Deploying the response force
    - Neutralizing the adversary
  - Primary response force is local law enforcement

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MITIGATION MEASURES CYBER, SCADA, & COMMUNICATIONS

- Install virus-protection software for email and internet access
- Categorize data and protect it accordingly
- Limit control of remote terminals to on-site or main terminals only
- Keep your operating system current
- Install a data log that can track all activity on a SCADA system
- Install intrusion detection software

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EMERGENCY RECOVERY

- Recovery plan must address the steps to be taken and provide an estimate of the time it will take for those steps to occur
- Management must consider the medium and long term steps that will allow the utility to completely recover from the disaster
  - Reduce the probability of additional injuries or damage
  - Perform emergency repairs based on priority demand
  - Return system to normal levels

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CRISIS COMMUNICATIONS

- Be the first to deliver the bad news
- When dealing with the media
  - Appoint one person to be the spokesperson
  - Prepare fact sheets and background information; have press release templates that can be quickly filled in with details
  - Set up pressroom that separates media from emergency command center
  - Be on time
  - Spell out your name and title when introducing yourself
  - Always repeat the question you are about to answer

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CRISIS COMMUNICATIONS

- When dealing with the media
  - Address fears by offering facts, not assumptions
  - Do not answer "what if" questions
  - Do not discuss costs of an incident
  - If all the facts are not known, admit that.
  - There is no such thing as "off the record"
  - Avoid assigning blame
  - Keep communications simple and direct to avoid confusion
  - Schedule a time for next update and meet this schedule even if there is no new information
  - Recognize and respect media deadlines

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EMERGENCY OPERATIONS PLAN

1

PROTECTING THE PUBLIC HEALTH

- Safe and reliable drinking water should be delivered to the public
- Should meet federal and state requirements
- Should be delivered in adequate quantities and at adequate pressures

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EMERGENCY OPERATIONS PLAN

- Also called EOP
- Identifies natural disasters and other emergencies that may strike a water system
- Assists water system in responding to emergencies quickly and effectively

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EMERGENCY OPERATIONS PLAN

- A carefully planned EOP will:
  - Reduce property damage
  - Minimize downtime
  - Prevent illness
  - Save lives
  - Reduce system liability
- Emergency response planning is essential

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EMERGENCY OPERATIONS PLAN

- EOP's include specific responses to:
  - Routine emergencies
  - Natural disasters
  - Accidents
  - Intentional man-made acts
  - Or any other incident that causes casualties, damage or disruption to the water system

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ROUTINE EMERGENCIES

- Line breaks
- Power outage
- Mechanical failure
- Water contamination

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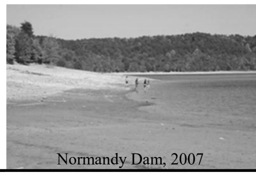
NATURAL DISASTERS

- Tornado
- Flood
- Earthquake
- Ice storm
- Drought


Tornado in Central Oklahoma, USA


Normandy Dam, 2007

7

ACCIDENTS

- Fire
- Chemical spill
- Explosion

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INTENTIONAL MAN-MADE ACTS

- Vandalism
- Terrorism
- Threats

Training Center 9

VULNERABILITY ASSESSMENT

- For those systems who have done the Vulnerability Assessment (VA), the EOP should include response actions to potential threats and malicious acts identified in your VA

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EMERGENCY OPERATIONS PLAN

- The Tennessee Division of Water Supply defines a document that prepares for an emergency response as an "Emergency Operations Plan".
- The US EPA refers to this document as an "Emergency Response Plan (ERP)"

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EOP

- State Rules require all community water systems to have an EOP
  - 1200-5-1-.17(7)
  - "… all community water systems shall prepare an emergency operations plan in order to safeguard the water supply and to alert the public of unsafe drinking water in the event of natural or man-made disasters."

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HISTORY

- After September 11, 2001 the federal government amended the Safe Drinking Water Act (SDWA) to add regulations on emergency preparedness for utilities, including community water systems

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HISTORY CONTINUED

- The BioTerrorism Act of 2002 added amendments to the SDWA that required the revision of water system emergency response plans to incorporate the results of the water system's vulnerability assessment

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HISTORY CONTINUED

- The Terrorism Act required that emergency response plans include plans, procedures and the identification of equipment that can be used in the event of a terrorist or other intentional attack on the water system

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EOP

- The EOP is a living document and should be reviewed and updated every two years
  - When there is a change to the water system configuration
  - Or when required by state or federal regulations

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EOP ELEMENTS

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EIGHT ELEMENTS OF EOP

- System Specific Information
- Roles and Responsibilities
- Communication Procedures
- Personnel Safety
- Alternate Water Source
- Equipment and Spare Parts
- Property Protection
- Water Sampling & Monitoring

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SYSTEM SPECIFIC INFORMATION

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SYSTEM SPECIFIC INFORMATION

- Water system info
- Maps & critical info
- Water source
- Water treatment process
- Distribution system
- Pumping facilities
- Storage facilities
- SCADA system
- Chemical inventory
- Materials/parts inventory
- Critical customers
- Largest customers
- Security features
- Communication equipment
- Office computer equipment

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WATER SYSTEM INFORMATION

- Lists general information about the water system
  - System name & PWSID#
  - Address and directions to plant, office and emergency operations center (EOC)
  - Number of employees and certified distribution operators
  - Utilities used by water plant: electric, phone, gas and cell phone companies
  - Number of connections and population served

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MAPS AND CRITICAL INFO

- EOP should reference
  - Location of distribution maps
  - Detailed plan drawings
  - Site plans
  - Valve and hydrant maps/books
  - Process flow diagrams
  - Operations reports
  - Operating manuals
  - Permits
  - Etc.

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MAPS AND CRITICAL INFO CONTINUED

- Maps and other critical plans may be kept at a secure location and given out only on a "need-to-know" basis at the discretion of the water system manager
- Maps need to be kept-up to date
- Keep duplicate copies secured off-site

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WATER SOURCE

- There are different templates for
  - Surface water
  - Well water
  - Purchased water
  - Spring water

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WATER SOURCE CONTINUED

- Give location for intake or master meter
- Intake pipe size
- Raw water pump info
  - Manufacturer, HP, capacity, year installed
- Well depth, diameter, static water levels
- Chemicals added at intake and quantity stored at intake building

WATER TREATMENT PROCESS

- Dimensions and detention times for
  - Flash mix
  - Flocculation basins
  - Sedimentation basins
  - Filters
- Chemicals added and point of application, especially chlorine and fluoride

DISTRIBUTION SYSTEM

- Population served
- Number of residential and commercial meters
- Miles of pipe
- Number of booster pumps and backflow preventers
- Peak, average and minimum daily demands

PUMPING FACILITIES

- Name/location
- Whether it is a building or underground vault
- Elevation
- Capacity
- Suction and discharge pressure

STORAGE FACILITIES

- Total number of elevated and ground level tanks
- Storage facility name/location
- Description
  - Welded steel, concrete, elevated, etc.
- Overflow or ground level elevation
- Capacity
- Level control
- Access and security

SCADA SYSTEM

- Manufacturer of SCADA, Computer hardware running SCADA, Network software, Firewall/Security software, Antivirus software
- Outside access to SCADA
  - Phone line, DSL, cable, other, none
- Is system password protected?

CHEMICAL INVENTORY

- Chemical brand and common name
- What process is it used for?
- Point of use
- Solid, liquid, gas?
- Strength
- Daily consumption
- Suppliers and their contact info

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MATERIALS & PARTS INVENTORY

- Description
- Serial # or VIN #
- Quantity
- Location

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CRITICAL CUSTOMERS

- Critical customers should be listed and prioritized based on community health issues
  - Hospitals, nursing homes, schools, daycares, etc.
- Name
- Description
- Address
- Phone #
- gal/day needed

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LARGEST CUSTOMERS

- List in prioritized order based on critical products or services to the community
- Name
- Description
- Address
- Phone #
- gal/day needed

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SECURITY FEATURES

- Location of buildings
- Gates, fences
- Doors/windows
- Locks/card key
- Alarm systems
- Security lighting
- Cameras/monitors

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COMMUNICATION EQUIPMENT

- Cell phones
- Pagers
- 2-way radios
- Satellite phones
- Laptops with phone service
- Need description, serial #, quantity and location for all these

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OFFICE COMPUTERS & EQUIPMENT

- Name and contact info for internal and outsource IT person
- Office computer hardware
  - Manufacturer
  - Serial #
  - Description/Processor
  - Location

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ROLES & RESPONSIBILITIES

CHAIN OF COMMAND
EMERGENCY RESPONDER COORDINATOR
INCIDENT COMMAND SYSTEM

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CHAIN OF COMMAND

- In an emergency, system personnel should know
  - Where to report
  - Whom to report to
  - What their responsibilities are during the emergency response

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CHAIN OF COMMAND CONTINUED

- Chain of command establishes lines of authority that preserve order and prevent confusion
- Check this document quarterly to confirm accuracy of personnel and phone numbers

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EMERGENCY RESPONSE COORDINATOR

- The first response in any emergency is to notify the lead person
  - This is the person at the top of the chain of command
  - Referred to as the Emergency Response Coordinator (ERC)
- An alternate ERC should be designated in case primary ERC is unavailable

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EMERGENCY RESPONSE COORDINATOR CONTINUED

- The ERC will asses the emergency and initiate the appropriate response actions
- The ERC will manage the entire emergency response unless an Incident Command Structure (ICS) facilitates a transfer of command

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EMERGENCY RESPONSE COORDINATOR
CONTINUED

- Other names given for lead person are
  - Emergency operations coordinator (EOC)
  - Emergency operations leader (EOL)
  - Incident commander (IC)
  - Water utility emergency response manager (WUERM)

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INCIDENT COMMAND SYSTEM

- In a major disaster, emergency or terrorist act, the ERC may need to initiate and/or defer to an Incident Command System (ICS)
- ICS is the model tool for coordinating the response efforts of several agencies as they work an emergency response

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INCIDENT COMMAND SYSTEM CONT

- If another agency takes over command in an ICS situation, the ERC and water system personnel remain in charge of all water system repairs and operations

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COMMUNICATION PROCEDURES

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COMMUNICATION PROCEDURES

- Internal contact list and responsibilities
- External contact list
- Emergency communications plan
- Effective communications
- Personnel safety
- Alternate water source
- Equipment and spare parts
- Property protection
- Water sampling and monitoring

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INTERNAL CONTACTS

- Contact information should be maintained for all people that may need to respond in an emergency
- List should be reviewed quarterly to keep up-to-date
- List should have home and cell number to contact people day or night
- Store back-up file/list at secure off-site location

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EXTERNAL CONTACTS

- Obtain cell phone or 24-hour emergency numbers for all external contacts
- List should be reviewed quarterly to keep up-to-date

EXTERNAL CONTACTS CONTINUED

- Local police
- Fire and first responders
- Local Government
  - Mayor, Chamber of commerce
- Local media
  - TV, radio, newspaper
- Utilities
  - Electric, natural gas, phone
- Cell phone companies
- Diesel fuel suppliers
- Outside vendors
  - Water plant pipes/parts, chemicals, SCADA
- Contractors
- Pump specialist
- Electricians & Plumbers
- Regulatory agencies
- Critical customers
- Water testing labs

Can you think of other external contacts?

EXTERNAL CONTACTS CONTINUED

- The TN Department of Homeland Security should be notified of any acts against the water system that may be caused by terrorist
- FBI becomes the lead agency in this case

EMERGENCY COMMUNICATIONS PLAN

- Communication procedures should be documented
- Alternate communications plans should be included in your EOP in the even that land lines, cell phones or walkie-talkies don't work
- Communicate with cellular companies on the availability of priority channels during an emergency
- Satellite phones should be considered an alternative

EMERGENCY COMMUNICATIONS PLAN CONTINUED

Emergency Communications Plan Template A-25 Example	
1	Walkie-talkie phones will the be first line of communication in an emergency. If walkie-talkie phones are inoperable, land phones, personal cell phones, and/or 2-way radios should be used to communicate with water system staff and external responders. Office managers will attempt to call phone company/cell phone company to request priority in restoring cell phone signals. (Two trucks and the office currently have three pair of 2-way radios. Two additional pair of 2-way radios are located in the manager's office at the Water System office.) Do not use 2-way radio for communications that should not be released to the public.
2	If phone and radio communication are inoperable, water system personnel should drive to the Emergency Operations Center (EOC) for emergency communication /assignments. Responders should communicate in person by walking or driving until phone service is restored.
3	Contact TEMA immediately for communication /emergency management assistance

EFFECTIVE COMMUNICATIONS

- Plan how you will communicate with customers and media before emergencies happen
- Designate a media spokesperson
- If 10% of the population speaks Spanish or another language, additional translated versions of public notifications should be made available

PERSONNEL SAFETY

- The water system should have procedures for securing the safety of utility personnel and the immediate community
- Schedule training sessions on
  - Basic safety procedures
  - Alarm response
  - First aid
  - Personal protection equipment (PPE) usage
  - Evacuation procedures

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ALTERNATE WATER SOURCE

- Identify the sources and procedures for obtaining a short-term and a long-term alternate water supply in the event of an emergency

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PUBLIC NOTICES

- Boil Water Notice
  - No alternate source is required
- Do Not Drink Notice
  - Alternate water source must be provided for drinking and food preparation
- Do Not Use Notice
  - Alternate water source must be provided for drinking, cooking, bathing and even fire fighting (in certain contamination scenarios)

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TANKER TRUCKS

- If tanker trucks are used to transport or store water as an alternate water source, make sure you allow time to disinfect the trucks properly
- See Appendix F for tanker truck disinfection procedures

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EQUIPMENT AND SPARE PARTS

- Identify these that can reduce the impact of an emergency
  - Vehicles
  - Chemicals
  - Tools
  - Spare parts
  - Special equipment
- All heavy equipment, portable generators, spare pumps, etc should be listed here

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EMERGENCY EQUIPMENT

- SCBA
- Toxic gas meters
  - Check and calibrate chlorine alarms and test
- Chlorine repair kits: A, B and/or C kits
  - Plan for chlorine repair parts and supplies
- All PPE for emergency

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PROPERTY PROTECTION

- Establish a procedure for locking down the facility and establishing a secure perimeter to the plant grounds and buildings
- Enter a potential crime scene with caution, if you believe suspects are still present, call 911

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PROPERTY PROTECTION CONTINUED

- The ERC will communicate with local police and emergency response teams to determine if the building should be locked down and site perimeter secured
- Look over the grounds and note any persons or vehicles in the vicinity
- Look, listen and smell for dangerous signs

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PROPERTY PROTECTION CONTINUED

- If you find victims, check out their physical condition, provide comfort and medical attention (if trained)
- Do not clean up, remove items or otherwise disturb the crime scene
- Document any statements/comments made by victims, suspects or witnesses on the scene

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PROPERTY PROTECTION CONTINUED

- After the site is secured and victims are stabilized, begin assessing potential contamination and/or damage to the water system
- Follow the water system's EOP

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WATER SAMPLING & MONITORING

- DWS and approved water lab should be consulted to determine appropriate testing and sampling
- Identify the certified operator or team (and alternates) who is/are responsible for taking samples

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WATER SAMPLING & MONITORING

- Sampling procedures should be outlined for:
  - Decision-making process to determine the tests to run
  - Location and/or source of test kits and/or sample containers
  - When to use preservatives or dechlorinating agents
  - Sample quantity to collect
  - Proper collection procedures

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WATER SAMPLING & MONITORING

- Provide a water sampling plan of your water distribution system
  - Sampling plan is to provide sample protocol and chain of custody
- Laboratory agreements are needed and contacts of outside labs are needed to secure monitoring requirements

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OTHER KEY ELEMENTS TO EMERGENCY PLANNING PROCESS

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WATER CONSERVATION & DROUGHT MANAGEMENT

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DROUGHT MANAGEMENT

- Public water systems and local communities should plan for conditions of low water supply by having an approved drought management plan in place
- *Local Drought Management Planning Guide for Public Water Suppliers*

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DROUGHT MANAGEMENT CONTINUED

- Plan may include, but not limited to the following restrictions
  - Use of water to wash any motor vehicle, motorbike, boat, trailer, or airplane or other vehicle
  - Use of water to wash sidewalks, driveways, decks, home siding, gutters, parking lots or other hard-surface
  - Use of water to irrigate lawns, trees, shrubs, plants and flowers

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DROUGHT MANAGEMENT CONTINUED

- Plan may include, but not limited to the following restrictions (cont.)
  - Use of water to fill indoor or outdoor swimming pools or hot-tubs
  - Use of water in fountain or pond except where necessary to support aquatic life
  - Use of water from a fire hydrant for other than fire fighting purposes

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WATER CONSERVATION

- Voluntary water conservation measures should be emphasized
  - Take short showers
  - Fix leaky faucets and running toilets
  - Don't allow water to run while brushing teeth or shaving
  - Collect rainwater for watering plants, gardens and flowers

WaterSense Meets EPA Criteria

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THREAT EVALUATION

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THREAT EVALUATION

- All threats should be taken seriously
- Threats may be reported or delivered in many different forms
  - Consumer complaint of water taste or odor
  - Witness account of tampering with water tank
  - Phone call from alleged perpetrator
  - Emergency room reporting patients with symptoms after drinking water

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THREAT IDENTIFICATION CHECKLIST

- Should be kept next to every phone at the office and water treatment plant
- If a threat is received, the checklist should be completed
  - See A-32 Threat Identification Checklist

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THREAT IDENTIFICATION CHECKLIST

- If you receive a suspicious letter or package, set it aside and do not open it
- Calmly instruct everyone to leave the room immediately
- Close the door
- Wash your hands with soap and water
- Notify your supervisor and/or call 911 if a suspicious substance is visible

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FOLLOW-UP EOP ACTIVITIES

- EOP approval and review date
  - Keep log on approvals
  - Update every two years
- EOP distribution
  - Keep copies numbered for control purposes
  - Keep log on who has what copy and where
- Training
  - Minimum training once a year

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TRAINING

- Orientation or classroom sessions
  - Basic instruction on EOP procedures
- Tabletop workshop
  - Fabricated event with actions/verbal responses and close with evaluation
- Functional exercise
  - Team of simulators develops a realistic major event and staff responds to the event
- Full-scale drills
  - More costly

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TRAINING CONTINUED

- Successful implementation of the EOP plan is going to depend on:
  - Training of employees and contacts
  - Yearly mock trial
  - Rotate personnel on the response teams
  - Annual revisions and updates

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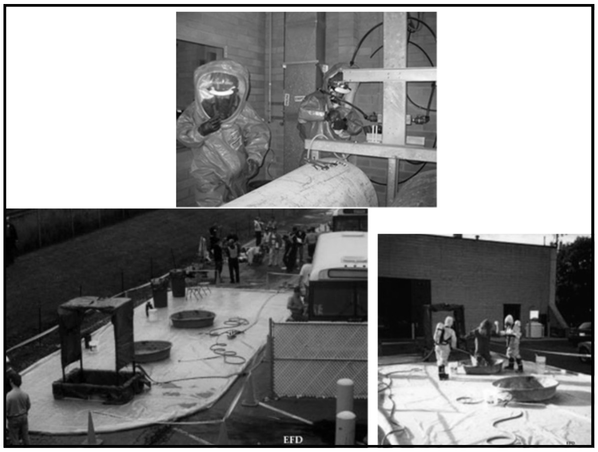

CHLORINE LEAK AT PLANT

- Water plant should have a current evacuation plan for chlorine gas evacuation
- Current plan should evacuate the plant grounds and a minimum ½ mile radius of affected area

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CHLORINE LEAK AT PLANT CONTINUED

1. Chlorine alarms go off and start a response
2. Phone call made of chlorine gas leak in plant
3. Operator makes investigation on site to chlorine room and alarms
4. Leak found and starts response

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CHLORINE LEAK AT PLANT CONTINUED

5. Incident commander notified and incident command started
6. Chlorine alarms acknowledged and evacuation started
7. Chlorine response and repair team activates to contain the leak; locate and isolate chlorine gas leak if possible

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CHLORINE LEAK AT PLANT CONTINUED

8. Water Plant evacuated and secured
9. Staging Area for incident command and safe zone established
10. Notify: 911, Hazmat, Police and Fire Department
11. Coordinate neighborhood evacuated with Police and Fire Department

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CHLORINE LEAK AT PLANT CONTINUED

12. Response Teams are working to isolate the chlorine leak
13. Chlorine repair team finds the leak and repairs the chlorine pressure diaphragm to the chlorine manifold
14. Area is checked for air monitor by gas detector for chlorine gas levels

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CHLORINE LEAK AT PLANT CONTINUED

15. Two hours into the event, the area is secure
    - Incident commander determines that the water plant is safe to return to normal water plant operations
16. Incident command is shut down
17. Normal plant operations and chlorine process are monitored for further compliance
18. Evacuation is canceled

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REFERENCES

- Emergency Operations Planning Guide, TN DWS along with templates can be found at: http://www.state.tn.us/environment/dws/security/svadocuments.shtml

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Section 8

Laboratory Methods

Laboratory Procedures

CSUS: Volume 1

Chapter 9

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.

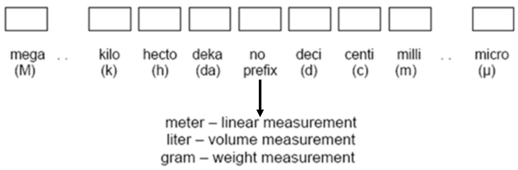
TN Design Criteria Part 6 Laboratory Facilities

- 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



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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

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Laboratory Units

- Chemical Names and Formulas
  - Compound (organic / inorganic)
    - A substance composed of two or more elements whose composition is constant
    - Examples: Aluminum sulfate $Al_2(SO_4)_3$
      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: $CaCO_3 \rightarrow Ca^{2+} + CO_3^{2-}$
      $HOCl \rightarrow H^+ + OCl^-$

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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









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Special – Purpose Glassware

- Filter Flasks
- Membrane Filter Holder
- Funnel



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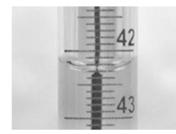
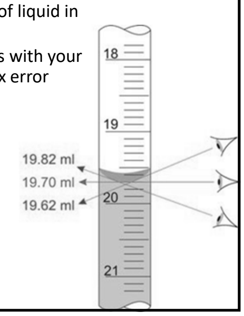
General Laboratory Equipment

- 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



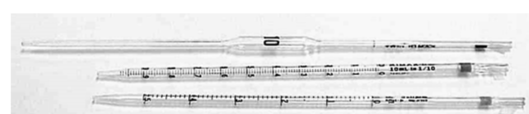


Using Laboratory Glassware

- 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 factions 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
      $7(H_2O)$ – 7 mol of water
- Molecular weight
  - The sum of the atomic weights of the elements in the compound
  - Molarity ≈ molecular weight
    - Example: H_2O = 2 x 1g (H) + 1 x 16g (O) = 18 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 ($Ca(OH)_2$)
  - 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 volatize 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

Instrument-Based Water Quality Tests

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

TN

pH

- *Power of Hydrogen*
- Negative logarithm of the hydrogen ion activity

  $pH = -\log [H^+]$
- 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.)

TN

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 pH = 1, then the hydrogen ion activity would be 10^{-1} or 0.1 mol/L,
- If pH = 14 , then $H^+ = 10^{-14}$ and OH- = 10^0
- If pH = 4, then $H^+ = 10^{-10}$ and OH- = 10^{-4}
- In a solution, both H^+ and OH^- ions are always present

TN

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)*

TN

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

TN

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

TN

Influences of pH

- Disinfection
  - As pH increases, disinfection efficiency decreases
  - HOCl → $H^+ + OCl^-$
  - 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

TN

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 scatted 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

TN

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)*

TN

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*

TN

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

TN

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

$$OH^- + H^+ \rightarrow H_2O$$
$$CO_3^{2-} + H^+ \rightarrow HCO_3^-$$
$$HCO_3^- + H^+ \rightarrow H_2CO_3$$

  - 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

TN

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

Chemistry of Treatment Processes

AWWA: Basic Science Concepts and Applications

Taste and Odor Removal

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

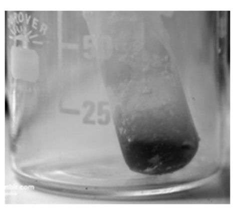
- Effective in removing iron and manganese and oxidizing organic and inorganic T&O causing materials
- Reaction in water produces
  - Oxygen (oxidizes organics and inorganics)
  - Manganese dioxide (MnO_2) to be removed during conventional treatment
- Add to water early for detention time (1-5 hours)
- Water turns pink when treated
  - As permanganate creates MnO_2, color will change
    - Pink → yellow → orange → 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 [$Al_2(SO_4)_3 \bullet 14H_2O$]
- 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

- $Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3\downarrow + 3CaSO_4\downarrow + 6CO_2$

$Al_2(SO_4)_3$	$3Ca(HCO_3)_2$	$2Al(OH)_3\downarrow$	$3CaSO_4\downarrow$	$6CO_2$
alum	natural bicarbonate alkalinity	aluminum hydroxide floc	calcium sulfate	carbon dioxide

- $Al_2(SO_4)_3 + 3Na_2CO_3 + 3H_2O \rightarrow 3Al(OH)_3\downarrow + 3Na_2SO_4 + 3CO_2$

$Al_2(SO_4)_3$	$3Na_2CO_3$	$3Al(OH)_3\downarrow$	$3Na_2SO_4$	$3CO_2$
alum	added carbonate alkalinity	aluminum hydroxide floc	sodium sulfate	carbon dioxide

- $Al_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 2Al(OH)_3\downarrow + 3\ CaSO_4\downarrow$

$Al_2(SO_4)_3$	$3Ca(OH)_2$	$2Al(OH)_3\downarrow$	$3CaSO_4\downarrow$
alum	added hydroxide alkalinity	aluminum hydroxide floc	calcium sulfate

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

$Fe_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightarrow 2Fe(OH)_3\downarrow + 3CaSO_4 + 6CO_2$

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

- 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

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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 [$Fe(HCO_3)_2$] 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

$$2Fe(HCO_3)_2 + Cl_2 + Ca(HCO_3)_2 \rightarrow 2Fe(OH)_2\downarrow + CaCl_2 + 6CO_2$$

ferrous bicarbonate	chlorine gas	natural bicarbonate alkalinity	ferric hydroxide	calcium chloride	carbon dioxide

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

$$MnSO_4 + Cl_2 + 4NaOH \rightarrow MnO_2 \downarrow + NaCl + Na_2SO_4 + H_2O$$

manganous sulfate; sodium hydroxide (caustic); manganese dioxide; sodium chloride; sodium sulfate; water

Aeration

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

$$4Fe(HCO_3)_2 + 10H_2O + O_2 \rightarrow 4Fe(OH)_3 \downarrow + 8H_2CO_3$$

ferrous bicarbonate; ferric hydroxide; carbonic acid

$$2MnSO_4 + O_2 + 4NaOH \rightarrow 2MnO_2 \downarrow + 2Na_2SO_4 + 2H_2O$$

manganous sulfate; sodium hydroxide; manganese dioxide; sodium sulfate

Permanganate

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

$$Fe(HCO_3)_2 + KMnO_4 + H_2O + 2H^+ \rightarrow MnO_2 \downarrow + Fe(OH)_3 \downarrow + KHCO_3 + H_2CO_3$$

$$3Mn(HCO_3) + 2KMnO_4 + 2H_2O \rightarrow 5MnO_2 \downarrow + 2KHCO_3 + 4H_2CO_3$$

$$3MnSO_4 + 2KMnO_4 + 2H_2O \rightarrow 5MnO_2 \downarrow + K_2SO_4 + 2H_2SO_4$$

Lime-Soda Ash Softening

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Types of Hardness

- Carbonate hardness
  - Caused by salts of calcium bicarbonate $Ca(HCO_3)_2$
- 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

$$MgCl_2 + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow + CaCl_2$$

magnesium chloride; lime; magnesium hydroxide; calcium chloride

- Calcium noncarbonate hardness is formed

$$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + 2NaCl$$

calcium chloride (from previous equation); soda ash; calcium carbonate; sodium chloride

Carbonate Hardness

- Only lime is required
- To remove calcium bicarbonate

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O$$

calcium bicarbonate; calcium hydroxide; calcium carbonate

- To remove magnesium carbonate hardness

$$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + MgCO_3 + 2H_2O$$

magnesium bicarbonate; lime; calcium carbonate; magnesium carbonate

$$MgCO_3 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + Mg(OH)_2 \downarrow$$

magnesium carbonate; lime; calcium carbonate; magnesium hydroxide

TN

Noncarbonate Hardness

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

$$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + Na_2SO_4$$

calcium sulfate; soda ash; calcium carbonate; sodium sulfate

$$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + 2NaCl$$

calcium chloride; soda ash; calcium carbonate; sodium chloride

TN

Lime-Soda Ash Softening

Main hardness causing ions

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

Chemical precipitation commonly used to soften water

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

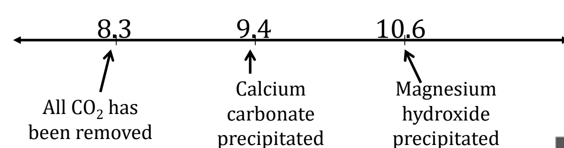
TN

Carbon Dioxide

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

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + H_2O$$

carbon dioxide; lime; calcium carbonate; water



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Recarbonation

- Reintroduction of CO_2 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
- CO_2 is bubbled into the water lowering the pH and removing the $CaCO_3$

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$$

calcium carbonate; carbon dioxide; calcium bicarbonate

TN

Recarbonation

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

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 \downarrow + H_2O$$

calcium hydroxide; carbon dioxide; calcium carbonate

- If too much CO_2 is added

$$Ca(OH)_2 + 2CO_2 \rightarrow Ca(HCO_3)_2$$

calcium hydroxide; carbon dioxide; calcium bicarbonate

TN

Scaling and Corrosion Control

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

$$Ca^{+2} + CO_3^{-2} \rightarrow CaCO_3 \downarrow$$
(noncarbonate hardness)

$$Ca^{+2} + 2HCO_3^{-} \rightarrow CaCO_3 \downarrow + CO_2 + H_2O$$
(carbonate hardness)

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

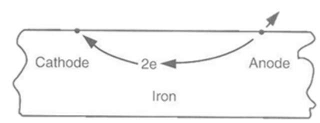
Scale-Forming Water ← **Stable Water** → **Corrosive Water**

- 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})

$$Fe \rightarrow Fe^{+2} + 2 \text{ electrons}$$



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

- CO_2 present in the form of carbonic acid
- pH will increase
- 1 mg/L of lime fed will remove 0.56 mg/L of CO_2

$$H_2CO_3 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$$
(carbonic acid, lime, calcium carbonate)

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

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$$
(calcium bicarbonate, lime, calcium carbonate)

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

$$LSI = pH - pH_s$$

TN

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**

TN

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

$$2Ca^{+2} + Na_4Y \rightarrow Ca_2Y + 4Na^{+}$$

Y represents the chelating agent

TN

Sequestration

- Chemical treatment process that controls scale
- Chemical sequesters (holds on to) scale-causing ions preventing them precipitating forming scale
  - Calcium, iron, manganese
- Any of several polyphosphates can be used
  - Sodium hexametaphosphate [$(NaPO_3)_6$] most common
- Sequestration is deliberate addition of chemicals to drinking water
  - Chelation is often considered a natural process

TN

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

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Chlorination

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Reaction in Pure Water

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

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

$$\underset{\text{hypochlorous acid}}{HOCl} \rightarrow H^+ + \underset{\text{hypochlorite ion}}{OCl^-}$$

– Hypochlorite ion works as disinfecting agent, only significantly (100x) weaker that 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

} Most important factors

- Other substances in the water
  - Reducing agents
    - Ammonia (NH_3)
    - Iron (Fe)
    - Manganese (Mn)
    - Hydrogen sulfide (H_2)
    - Dissolved organic materials

Reaction with Ammonia (NH_3)

- 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

$$\underset{\text{ammonia}}{NH_3} + HOCl \rightarrow \underset{\text{monochloramine}}{NH_2Cl} + H_2O$$

$$\underset{\text{monochloramine}}{NH_2Cl} + HOCl \rightarrow \underset{\text{dichloramine}}{NHCl_2} + H_2O$$

$$\underset{\text{dichloramine}}{NHCl_2} + HOCl \rightarrow \underset{\text{trichloramine}}{NCl_3} + H_2O$$

Reaction with Ammonia (NH_3)

- 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 [$Fe(HCO_3)_2$]
- Easily removed by chlorination

$$\underset{\text{ferrous bicarbonate}}{2Fe(HCO_3)_2} + Cl_2 + \underset{\text{calcium bicarbonate}}{Ca(HCO_3)_2} \rightarrow \underset{\text{ferric hydroxide}}{2Fe(OH)_3} \downarrow + CaCl_2 + 6CO_2$$

- 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

$$MnSO_4 + Cl_2 + 4NaOH \rightarrow MnO_2 + 2NaCl + Na_2SO_4 + 2H_2O$$

manganous sulfate; sodium hydroxide; manganese dioxide; sodium sulfate

- 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 (H_2S)

- Frequently found in groundwater sources
  - Can impact taste at 0.05 mg/L
  - Rotten egg smell at 0.5 mg/L
  - Fatal in inhaled at 0.1-0.2% concentration in air
  - Flammable above 4.3% concentration in air
- Chlorine reacts with H_2S in one of two ways depending pH

$$Cl_2 + H_2S \rightarrow 2HCl + S$$

  - Instantaneous reaction that occurs at high pH
  - Formed sulfur causes milky-blue turbidity that can be removed by coagulation & filtration

$$4Cl_2 + H_2S + 4H_2O \rightarrow 8HCl + H_2SO_4$$

preferred reaction

Reaction with Hydrogen Sulfide (H_2S)

$$Cl_2 + H_2S \rightarrow 2HCl + S$$

$$4Cl_2 + H_2S + 4H_2O \rightarrow 8HCl + H_2SO_4$$

- If pH ≈ 6.4, all sulfides are converted to sulfates
- At pH ≈ 7.0, 70% of H_2S turns to H_2SO_4 and other 30% turns to elemental sulfur
- At pH ≈ 9.0-10.0, 50% H_2S turns to H_2SO_4 and 50% turns to elemental sulfur (S)

Sources of Chlorine

- Gaseous chlorine (Cl_2)
  - 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

$$Cl_2 + 2H_2O \rightarrow 2HOCl + HCl$$

chlorine gas; hypochlorous acid; hydrochloric acid

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

$$Ca(OCl)_2 + 2H_2O \rightarrow 2HOCl + Ca(OH)_2$$

calcium hypochlorite; hypochlorous acid; lime

Sources of Chlorine

- Sodium hypochlorite (NaOCl)
  - Clear, greenish-yellow liquid chlorine solution

$$NaOCl + H_2O \rightarrow HOCl + NaOH$$

sodium hypochlorite; hypochlorous acid; caustic

Section 10

Feed Rate Math

Chemical Feeders

Fleming Training Center
TN Department of Environment & Conservation

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 the be treated is 2,100,000 gpd, what should the lb/day setting be on the dry alum feeder?

$$\text{loading rate}, \frac{\text{lb}}{\text{day}} = (\text{flow, MGD})\left(\text{conc.}, \frac{\text{mg}}{\text{L}}\right)\left(8.34\,\frac{\text{lb}}{\text{gal}}\right)$$

$$\frac{\text{lb}}{\text{day}} = (2.10\ \text{MGD})(8\ {}^{\text{mg}}/{}_{\text{L}})(8.34\ {}^{\text{lb}}/{}_{\text{gal}})$$

$$\frac{\text{lb}}{\text{day}} = 140\ {}^{\text{lb}}/{}_{\text{day}}$$

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.

$$\text{average} = \frac{5\text{g} + 7\text{g} + 5\text{g}}{3} = \frac{17\text{g}}{3} = 5.67\text{grams}$$

$$\left(\frac{5.67\ \cancel{\text{grams}}}{1\ \cancel{\text{minute}}}\right)\left(\frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}}\right)\left(\frac{24\ \cancel{\text{hr}}}{1\ \text{day}}\right)\left(\frac{1\ \cancel{\text{kg}}}{1000\ \cancel{\text{g}}}\right)\left(\frac{1\ \text{lb}}{0.454\ \cancel{\text{kg}}}\right)$$

$$\frac{(5.67)(60)(24)(1)(1)}{(1)(1)(1)(1000)(0.454)} = \frac{8164.8}{454}$$

$$17.98\ \text{lb/day}$$

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

$$\text{feed rate, } {}^{\text{gal}}/_{\text{day}} = \frac{\text{chemical feed rate, } {}^{\text{lb}}/_{\text{day}}}{\text{lb chemical}/_{\text{gal solution}}}$$

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.

$$\text{Loading Rate } \frac{\text{lb}}{\text{day}} = (\text{flow, MGD})(\text{conc, mg/L})(8.34 \text{ lb/gal})$$

$$\frac{\text{lb}}{\text{day}} = (1.52 \text{ MGD})(7 \text{ mg/L})\ (8.34 \text{ lb/gal})$$

$$\frac{\text{lb}}{\text{day}} = 88.7376\ {}^{\text{lb}}/_{\text{day}}$$

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).

$$\frac{\text{mL}}{\text{min}} = \frac{(\text{Flow, MGD})\left(\text{dose}, \frac{\text{mg}}{\text{L}}\right)\left(3.785\frac{\text{L}}{\text{gal}}\right)\left(1{,}000{,}000\frac{\text{gal}}{\text{MG}}\right)}{\left(\text{liquid}, \frac{\text{mg}}{\text{mL}}\right)\left(1440\frac{\text{min}}{\text{day}}\right)}$$

**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?

$$\frac{\text{mL}}{\text{min}} = \frac{(\text{Flow, MGD})\left(\text{dose}, \frac{\text{mg}}{\text{L}}\right)\left(3.785\frac{\text{L}}{\text{gal}}\right)\left(1{,}000{,}000\frac{\text{gal}}{\text{MG}}\right)}{\left(\text{liquid}, \frac{\text{mg}}{\text{mL}}\right)\left(1440\frac{\text{min}}{\text{day}}\right)}$$

$$\frac{\text{mL}}{\text{min}} = \frac{(2.12\text{MGD})\left(1.4\frac{\text{mg}}{\text{L}}\right)(3.785\frac{\text{L}}{\text{gal}})(1{,}000{,}000\frac{\text{gal}}{\text{MGD}})}{(1175.5\frac{\text{mg}}{\text{mL}})(1440\frac{\text{min}}{\text{day}})}$$

$$\frac{\text{mL}}{\text{min}} = \frac{11{,}233{,}880\text{mg}}{1692720\frac{\text{mg}\cdot\text{min}}{\text{mL}}} = \quad 6.64\frac{\text{mL}}{\text{min}}$$

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?

$$\%\ \text{stroke} = \frac{\text{desired flow}}{\text{maximum flow}} \times 100$$

$$\%\ \text{stroke} = \frac{8\ \text{gpm}}{90\ \text{gpm}} \times 100$$

$$\%\ \text{stroke} = 8.9\%$$

Chemical Feeders

1. A flow of 1,850,000 gpd is to be treated with alum. Jar tests indicate that the optimum alum dose is 10 mg/L. If the liquid alum contains 640 mg alum per milliliter solution, what should be the gallons per day setting for the alum solution feeder?

2. Jar tests indicate that the best alum dose for a unit process is 10 mg/L. The liquid alum contains 5.40 lb alum per gallon of solution. What should the setting be on the solution chemical feeder (in milliliters per minute) when the flow to be treated is 3.45 MGD?

3. The average gallons of polymer solution used each day at a treatment plant is 88 gpd. A chemical feed tank has a diameter of 3 ft and contains solution to a depth of 3 ft 4 inches. How many days' supply are represented by the solution in the tank?

4. The maximum pumping rate is 110 gpm. If the required pumping rate is 40 gpm, what is the percent stroke setting?

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 KMnO4. 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		