Tailored for NM Basic Wastewater Operators – Levels 1 & 2

# DISINFECTION and DECHLORINATION for WASTEWATER

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# Disinfection in Wastewater for Level 1 & 2 Operators

## Topics



 

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# Disinfection

- All wastewaters contain microorganisms or microbes
- Some are beneficial and needed for natural processing of the wastewater
- Others, called **pathogens**, are harmful and need to be removed or sterilized because they cause diseases
- Sterilization of the water causes ALL microorganisms to die
- Disinfection destroys or neutralizes the pathogens that cause the disease
- Wastewater discharges must be disinfected to protect:
- Public Water Supplies
- Recreational & Reuse receiving waters
- Aquatic and other wildlife
- Pathogens enter the system through people who have the diseases
- Why wastewater was used to track COVID
- Three major categories of water-borne pathogens:
- Bacteria
- Cholera, Shigella, Salmonella, Typhoid, Dysentery, Meningitis
- Viruses
- Hepatitis, Polio, Norwalk, Rotavirus, Adenovirus, COVID
- Protozoa
- Giardia lamblia, Cryptosporidium parvum
- Disinfection is one of the primary goals for wastewater treatment
- Several methods are used
- Chlorine ($Cl_2$), UV, Ozone ($O_3$), Chlorine Dioxide ($ClO_2$)
- Chlorine and UV are two most common disinfection methods in US
- $Cl_2$ disinfection methods use Concentration-Contact Time (CT) calculation
- AKA - Kill formula; Effective Disinfection (ED) formula
- Formula (mg-min/L or ppm-min/L):

$$CT = Conc.(C) \times Time(T)$$

- Concentration calculated from CT tables or permit requirements
- Time calculated from detention time, flow derived from peak hourly flow or design of contact chamber/basin/tank
- pH and temperature must be taken into consideration
- Old rule of thumb you will hear based on design criteria

***>2.0 after 20-min contact time***

- EPA provides CT tables according to log inactivation to determine required contact time for permitting.
- These tables and log values are used in advanced wastewater and drinking water classes.

 

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- New Mexico does not specify a fixed detention time in NMAC 20.7.4 or 20.6.2. NM permits specify:
    - CT must be sufficient to meet fecal coliform limits
    - CT must be calculated using peak hour flow
    - CT must be based on the disinfection method used
    - CT must be demonstrated through design documents
    - NM follows the EPA CT concept, not a fixed minute rule

# Chlorine

- Most widely used because pathogens are most sensitive to its effects and readily available
- Comes in different forms:
    - Gas - cheapest per pound
    - Powder, granules, tablets
    - Liquid - (Bleach) most expensive
- Requires safety equipment & precautions as a hazard assessment
- Corrosive, Oxidizer. Toxic
- Requires dechlorination before discharged into waterways
- Hazards
    - Corrosive
    - Oxidizer
    - Toxic
- Used for:
    - Disinfection
    - BOD removal
    - Grease removal
    - Odor control
    - Trickling Filters (flies)
    - Sludge bulking
    - Algae control in weirs

## Chlorine Gas


- Gas (pure Chlorine, $Cl_2$) comes in:
    - Rail Car
    - 1 Ton cylinders
    - 150 lb cylinders
- Properties:
    - 1 ½ times heavier than Water
    - 2 ½ times heavier than Air - LDL 0.1%
    - Non-flammable
    - Greenish yellow gas
    - Pungent odor
    - Irritant - PEL = 1 ppm; IDLH 10 ppm
    - Corrosive - forms HCl with moisture in air

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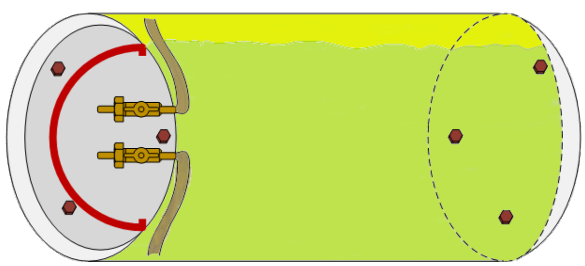
- Leaks can be detected using concentrated ammonia (white vapor reaction)
- Cheapest but more hazardous
- Gas is compressed while filling the cylinder, which turns into a liquid inside the cylinder.
  - 15% gas 85% liquid
- Vaporizes at room temperature
  - Able to expand 460 times its liquid volume when vaporized
- Will freeze if drawn off too quickly
- Only way to accurately measure it, is by ***weight***

## *1 Ton Cylinders*

- Designed to lay on their sides during transportation, handling and use
- Must be handled using a hoist, which is part of the specially built storage building.
- Stored on trunnions and/or scales to prevent rolling around while allowing them to be rotated for proper valve positioning during connection.
- Valves are protected by a bowl shaped cover (bonnet) that attaches to the end of the container and should be secured and in place during transportation and handling of the ton cylinders.
- Only remove covers to connect to the feed system.
- Have two valves on the end, which allows for the feeding of either gas or liquid chlorine.



- Top valve at the 12 o'clock position draws off chlorine gas
- Bottom valve at the 6 o'clock position will feed liquid chlorine to an evaporator
- **Holds 2,000 lbs of chlorine, but weighs ~ 3,700 lbs when full.**
- Can deliver <u>**400 lbs/day/cylinder**</u> without any trouble.
- Above that feed rate, frosting and freezing will occur.
- When feeding chlorine as a liquid, the withdrawal rate is much higher at **9,600 lbs/day/cylinder** when using an evaporator.
- Every gas cylinder will have 6 (three on each end) “fusible plugs” that is designed to melt at 157°F.
- Room temperature to be kept between 60°F and 120°F.
- Room must be clean and dry
- Reacts violently with:
  - grease,

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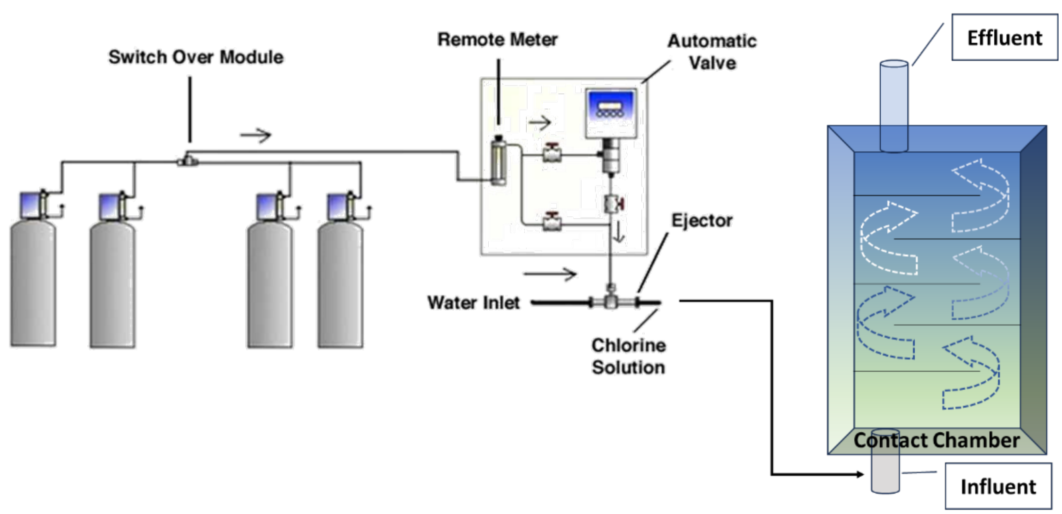
- turpentine,
- ammonia,
- hydrocarbons,
- metal filings.
- Do not use organic solvents or greases on equipment
- Only use wrenches made for these valves
- *Never* reuse washers

## *150 lbs Cylinders*


- Stored in the upright position and secured by chains.
- **Total weight of a 150 lb-cylinder is about 285 pounds.**
- Ensure valve is not damaged when handling the cylinder.
- Protective hood stays in place to protect the valve.
- Special dollies with safety chains for transporting chlorine cylinders.
- ***Feed rate is limited to 40-42 lbs/day***
- One safety plug in valve
- Do not expose to direct sunlight
- Other rules for 1-Ton apply

## *Chlorine Gas Flow Chart for 1-ton cylinders*



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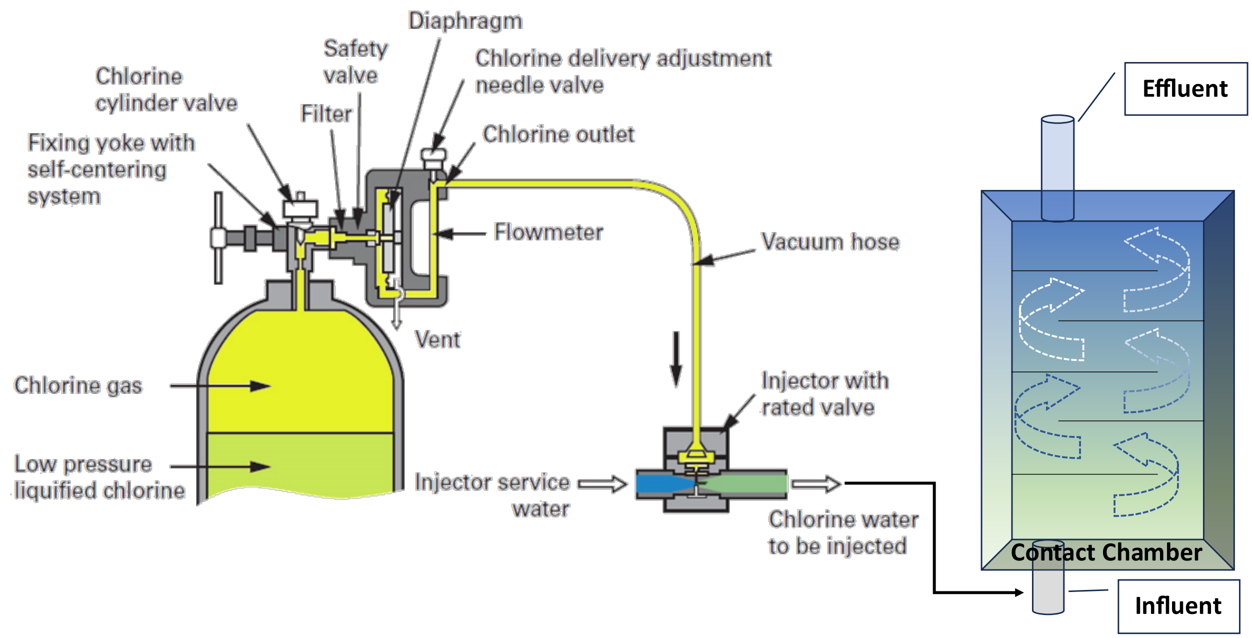
## *Chlorine Gas Flow Chart for 150-pound cylinders*




# Hypochlorination

## *Chlorine Solids*



- Tablet or granulated powder
  - HTH or High-Test Hypochlorite, $OCl^-$ , $ClO^-$
  - Calcium Hypochlorite most common, $Ca(ClO)_2$
  - Pure - 99.2% available chlorine
  - 65-70% available chlorine most widely used
  - 2-3 times more expensive, per pound of chlorine, than chlorine gas
- Properties
  - White, yellow or blue-speckled powder or tablet
  - Strong  Oxidizer (do NOT store with hydrocarbons)
  - Corrosive, especially to metals and clothing
- Don't Mix These Chemicals! What Happens When You Mix Brake Fluid and Chlorine? TKOR Shows You! https://youtu.be/jY63x9rPLek

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## *Chlorine Powder & Tablet Feed Systems*

- Must be turned into liquid and stored
- Storage only good for 30 days
- For small systems <500,000 gpd
- Can be used for algae and odor control
- Commonly used where gas systems are impractical
- Requires proper mixing, solution tanks, and feed pumps
- Solid chlorine is a **strong oxidizer**

## *Liquid Chlorine*



- Sodium Hypochlorite is most common, NaOCl or NaClO, some Calcium Hypochlorite is used
- Totes, Barrels, Bottles, Tankers
- Household bleach is 5.25% available chlorine
- Commercial and Industrial strength chlorine is 12-15%
- Most costly per pound of available options
- Clear to yellow color
- Corrosive, irritant, toxic
- Can lose up to 4% of its available chlorine content per month
- Should not be stored for more than 60 to 90 days
- Will leave calcium, magnesium or sodium salts/carbonates behind

***Sodium Hypochlorite Feed System***

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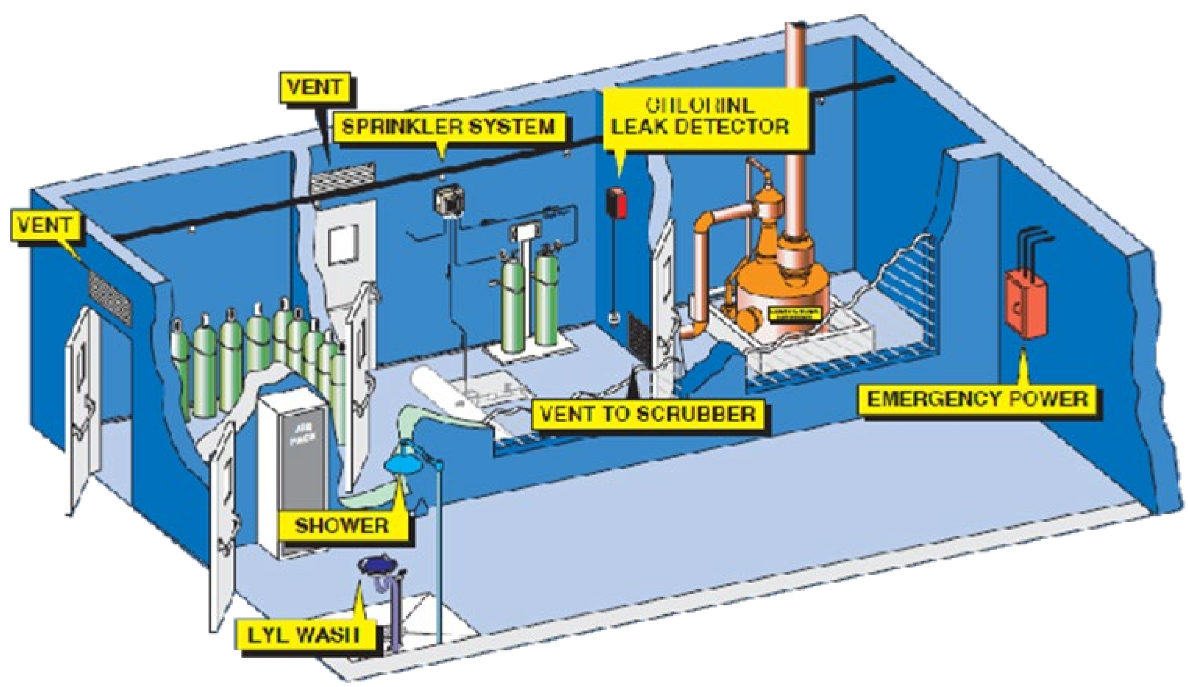
## Chlorine Safety


- Use buddy system
- Storage and cylinder room should be separate from feeding room
- Building *<u>requires</u>* ventilation and scrubber
- PPE
  - Goggles and/or Face Shield
  - Chemical Resistant Gloves
  - Chemical Apron
  - Escape or cartridge respirator
  - SCBA
- Requires <u>both</u> **Hazard Assessment** and **Emergency Preparedness Plan**
- Chlorine detector
- Ventilation & light switches, detector readout and warning lights on outside of building
- Safety Shower nearby
- Eye wash station nearby
- Leak detection kit
- Emergency Repair kits


### *Chlorine Safety Room Example*



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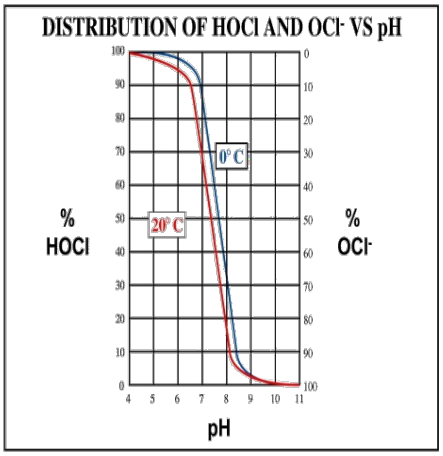
## Chemistry of Chlorine



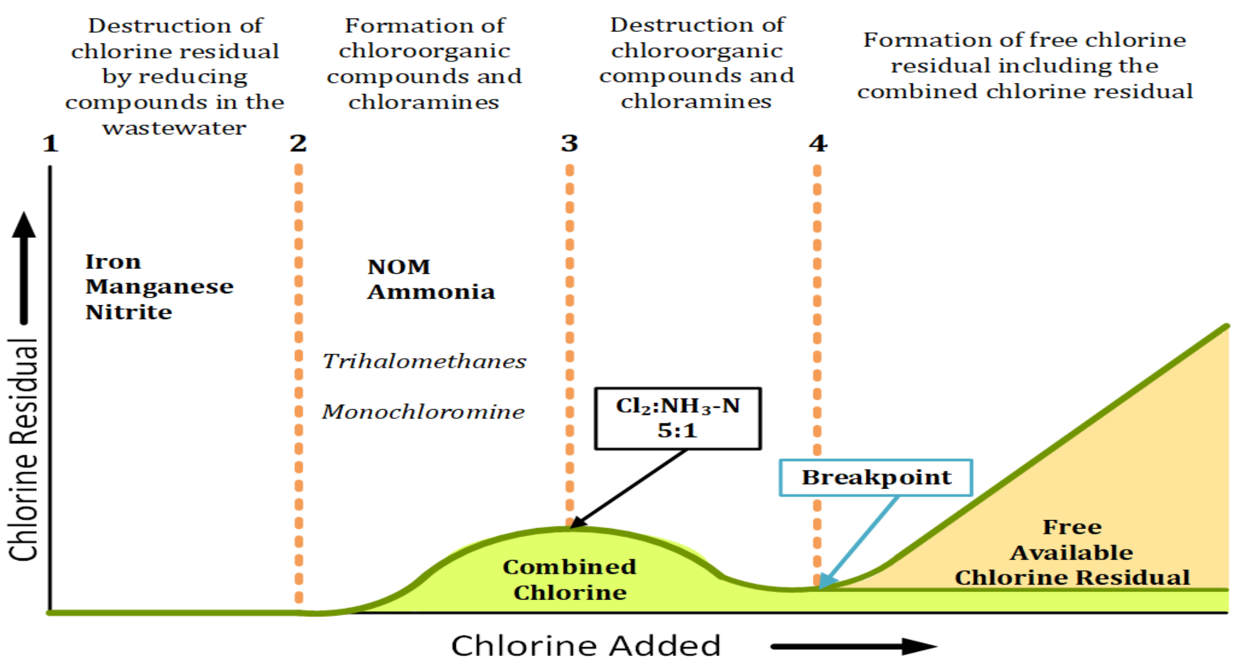

- Hydrolysis occurs when chlorine ($Cl_2$) reacts with water ($H_2O$) producing:
  - Hypochlorous acid (HOCl) and
  - Hydrochloric acid (HCl)
- Reaction with water

**$Cl_2 + H_2O \rightarrow$ HOCl (Hypochlorous) + HCl (Hydrochloric)**

- Which breaks down further

$H^+$ (Hydrogen ions) + $OCl^-$ (hypochlorite ions) + $Cl^-$ (Chlorine ions)

- Reacts with reducing compounds, such as organic matter and inorganic contaminants (iron, manganese, $H_2S$, & ammonia)
- Uses the chlorine concentration available until all compounds have been destroyed by the chlorine
- Once reducing agents in the wastewater have been destroyed, chlorine residual begins to accumulate
- Chlorine concentration (C) and contact time (T) impact the disinfection process the most




*NOM = Natural Organic Matter*

- Between points 1 and 2 on the breakpoint curve above is where the chlorine demand occurs. Chlorine is being used to consume the iron, manganese and nitrites in the wastewater. There cannot be a chlorine residual until all the demand has been satisfied.

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- Between points 2 and 3 on the curve, the organic compounds and ammonia react with the chlorine, creating chloroorganic compounds, such as trihalomethanes (THMs) and chloramines, such as monochloramine. This reaction will peak at a ratio of 5:1 ($Cl_2$:$NH_3$-N).
- Between points 3 and 4, a reduction in chlorine residual occurs until all the chloroorganic and ammonia are oxidized.
- Point 4, where the curve bottoms out, is known as the breakpoint. Any chlorine added after breakpoint occurs creates a free available chlorine residual that will increase at a linear pace. The free chlorine residual also includes the combined chlorine residual.

## Chlorine Dosage = Demand + Residual

- **Chlorine demand** is the difference between the amount of chlorine added to the water and the amount of residual chlorine remaining after a given contact time.
  - Demand may change with dosage, time, temperature, pH, and the nature and amount of the impurities within the water.
- **Chlorine residual** is the concentration of chlorine present in the water after the demand has been satisfied.
  - Expressed in terms of the **total chlorine residual (TCR)**, which includes both the free and combined (chemically bound) chlorine residuals.
  - *Combined*, or chemically bound, chlorine residuals are composed of:
  - Free chlorine
  - Ammonia
    - Reacts with hypochlorous acid to form the Chloramines
  - Chloramines
    - Monochloramine, $NH_2Cl$
    - Dichloramine, $NHCl_2$ - best disinfectant
    - Trichloramine, $NCl_3$
- **Chlorine dosage** is the amount of chlorine added to the water.
  - Measured in mg/L
  - Density, specific gravity and percent available chlorine must be taken into consideration.
  - Remember: 1% = 10,000 mg/L (ppm)

### *Examples:*

1. Find the chlorine demand of an effluent if the initial chlorine dose is 8.6 mg/L and the residual is 1.3 mg/L.

Demand = Dosage - Residual

8.6 mg/L - 1.3 mg/L =

$$\boxed{7.3\ mg/L}$$

 

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2. In order to maintain an adequate chlorine residual, the chlorine dose must be 9 mg/L when the flow is 0.4 MGD. Find the chlorinator setting, in lbs/day.

$$lbs/day = MGD \times 8.34 \times mg/L$$

$$lbs/day = 0.4\ \text{MGD} \times 8.34 \times 9\, mg/L$$

$$\boxed{30\ lbs/day}$$

## Chlorine - Factors Affecting Disinfection

- Chlorine concentration (C)
  - Lower concentrations, longer contact time
- Contact time (T)
  - Slower contact time, higher dose
  - Varies from state to state, but it is generally 15 minutes of CT at peak hour design flow or 30 minutes of CT at average daily design flow
  - Remember (mg-min/L or ppm-min/L):
- $CT = Conc.(C) \times Time(T)$
- Water temperature
  - Lower temperature, process slows, but is more stable;
    - more time but not necessarily more concentration
  - Higher temperature, process increases,
    - residual dissipates more rapidly, higher concentration needed
- Water pH
  - Lower pH, more hypochlorous formation better disinfection when using gas
  - Higher pH, more chlorite formation when using NaOCl and actually raises pH
- Foreign substances in the water
  - Only effective if it is able to come into contact with the microbe it is intended to kill
  - Any impurities in the water can shield the microbe from the chlorine

## Chlorine Measurement


- **Total Residual Chlorine (TRC) =**

  **Free Chlorine (FCR) + Combined Chlorine (CCR)**
- Colorimetric test as Free or Total chlorine in mg/L
- Testing ***must begin*** within 15 min of sampling
- 2 Methods are Amperometric Titration and Colorimetric DPD
- Amperometric Titration
  - Mainly used in laboratories
  - Equipment costs and training prohibitive
  - $H_2S$ and methane will interfere
- N,N-diethyl-p-phenylenediamine, **DPD**
  - Most commonly used
  - Turns shades of light pink to magenta (dark red/purple)

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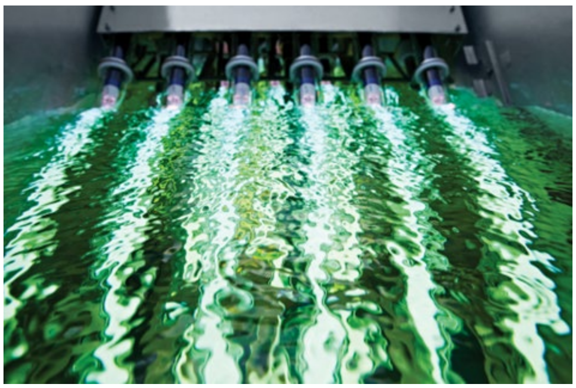
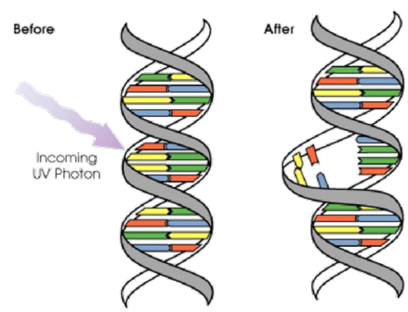
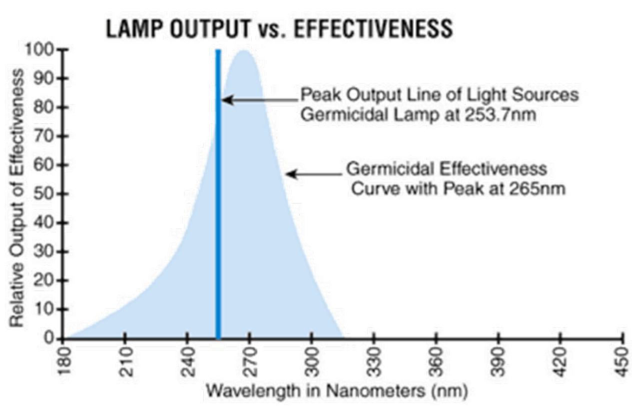
- N,N-diethyl-p-phenylenediamine, **DPD**
  - Flash of dark color to clear may mean extreme residual > 5 mg/L
  - Must perform calibration check prior to sampling every day before 1st use
  - Uses 'blank' to allow for turbidity when using spectrograph equipment

# Ultraviolet UV



- Rapidly overtaking Chlorine as most common disinfection method until COVID
- Closed Vessel or Open channel systems
- Advantages
  - Less safety hazard
  - No harmful by-products
  - Shorter contact time
  - Uses less water than chlorine
- Disadvantages
  - Consumes more energy than chlorine
  - Turbidity must remain low: TSS < 30 mg/L
  - Aggressive maintenance program
  - Requires back-up power source
- Damages the DNA of the organisms
  - no longer able to grow or reproduce
  - Some organisms can 'repair' the damage after reentering sunlight
- UV-C rays at 100–280 nm wavelength




- UV radiation is generated by passing energy through mercury vapor
- Low-pressure amalgam lamps produce light at 254 nm
- Medium pressure lamps produce light at multiple wavelengths w/15-20x germicidal of LP
- Optimum wavelength to effectively inactivate microorganisms = 250 - 270 nm
- Flow must remain constant with little turbulence

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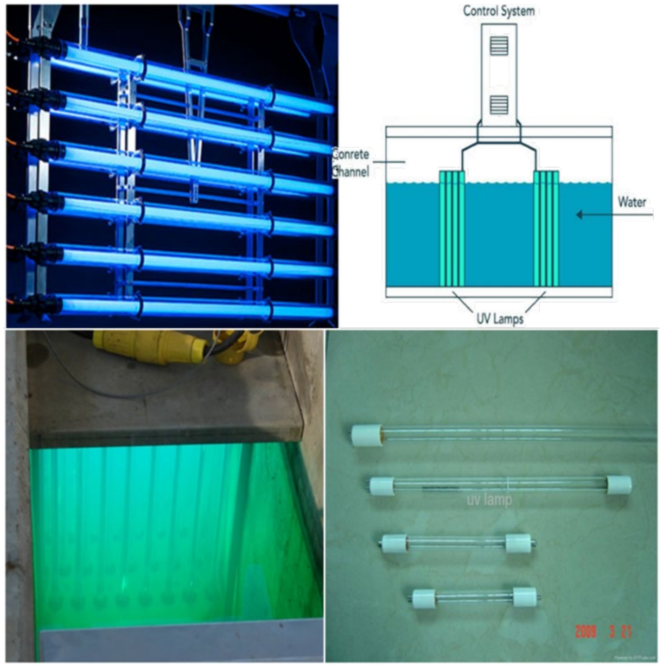
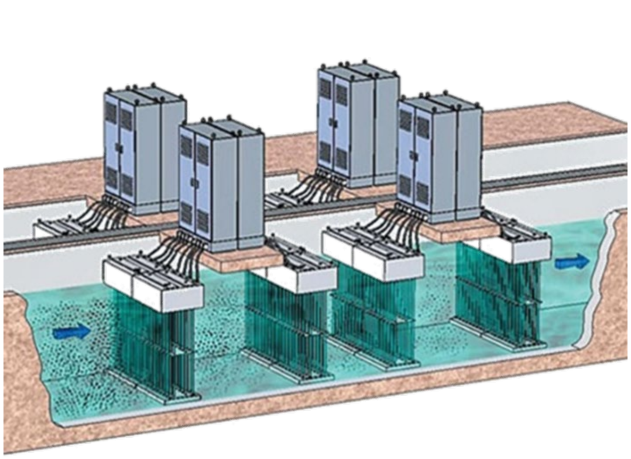
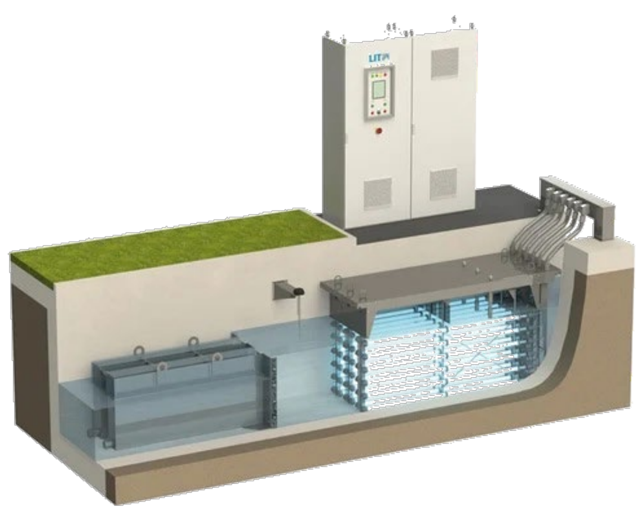



- Channel should be sized just wide enough to hold the bank or series of banks
- System referred to as 'contact reactor'
- Low-pressure (LP) or medium-pressure bulbs (MP) enclosed in quartz cover for protection
- Each bulb connected a ballast
- Lifetime of bulb ~ 12,000 hours
- Squeegees or wiper system to control build-up on quartz sleeves
- Consists of multi-bulb 'rack' or module systems
- Multiple modules forms banks
- Racks either parallel (horizontally) or perpendicular (vertically) to water flow in channel
- Flap gates, baffles, and weirs used to maintain constant water level & flow
- Light transmittance and intensity, flow, and turbidity measuring instruments required for process control
- Monitor TSS with either in-line system or frequent testing
- Ferric chloride for phosphorus removal cannot be used as it will 'stain' quartz sleeves
- Systems with naturally hard water will need to be cleaned more frequently
- Back-up generator required by EPA (make sure to test)
- Coliform testing for effectiveness in CFUs/100 mL or MPN/100 mL





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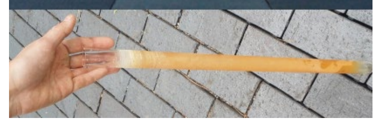
## UV Disinfection OEM & PM

- Bulbs, ballasts, and modules securely seated in channel or closed vessel with hatch closed before powering on
- Replace bulbs and ballasts as they fail or reach maximum hours
- Frequently monitor sensors and calibrate weekly
- Keep reactor chamber/channel clean from algae and deposits
- Inspect wiper/squeegee for proper operation and run times (manually run)
- Clean quartz coverings as required with citric acid, CLR, phosphoric or other weak acid in dip bath with air scour
- Yearly electrical inspection



## UV Disinfection Safety

- Although sealed, water and electricity do not mix
  - Lock Out/Tag Out when servicing!
- Will cause 'sun burns'→ sunscreen or protective clothing
- UV-C rated safety glasses/goggles/face-shield
  - NEVER look directly at bulbs when powered on w/o eye protection
- Contains mercury
  - Mercury spill kit & PPE
- Sharps disposal & PPE
- Special disposal for used bulbs
- PPE for chemical cleaning
- PPE and safety procedures when cleaning channels

# Dechlorination

- Free, uncombined chlorine is rarely found in wastewater due to characteristics of WW and chemical reactions
- Must be performed before discharging to receiving waters
- Commonly used methods are
  - Granular Activated Carbon
  - Agitation & Aeration in the form of step aeration or air diffusers
  - Sunlight
  - Sulfur Dioxide gas
  - Sodium Salts used to form Sulfur Dioxide in solution
    - Sodium Sulfite ($Na_2SO_3$ )
    - Sodium Metabisulfite ($Na_2S_2O_5$ ) powder or a 38% aqueous solution
    - Sodium Bisulfite ($NaHSO_3$ )
    - Sodium Thiosulfate ($Na_2S_2O_3$ )

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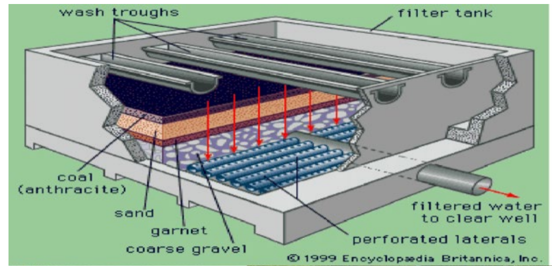
# Natural Dechlorination




- Requires long detention and contacts times
- Granular Activated Carbon
  - Part of tertiary treatment processes in rapid sand filters
- Agitation & Aeration in the form of step aeration or air diffusers
  - Added advantage of increasing DO
  - Coarse bubble diffusers at end of contact chamber
- Sunlight
  - Must be shallow (inches) in depth
  - Often combined with step aeration

# Chemical Dechlorination

- Usually a 1:1 ratio
- Faster reactions but prone to overdosing and more safety hazards
- Overdosing
  - Prevention
  - pH may drop below 6.0-8.0 normal range
  - DO lowered below minimum 4.0 mg/L
- Sulfur Dioxide ($SO_2$):
  - Most commonly used
  - Non-flammable, colorless gas
  - Pungent Odor
  - Irritant & Corrosive
- Sulfur dioxide gas (sulfonator) similar to chlorine gas (chlorinator) design and safety precautions

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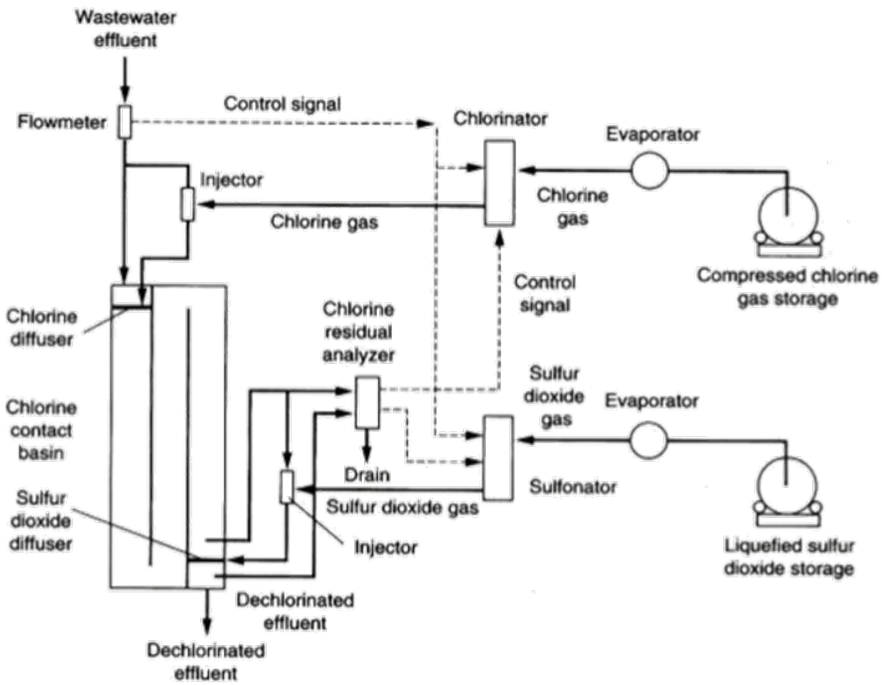
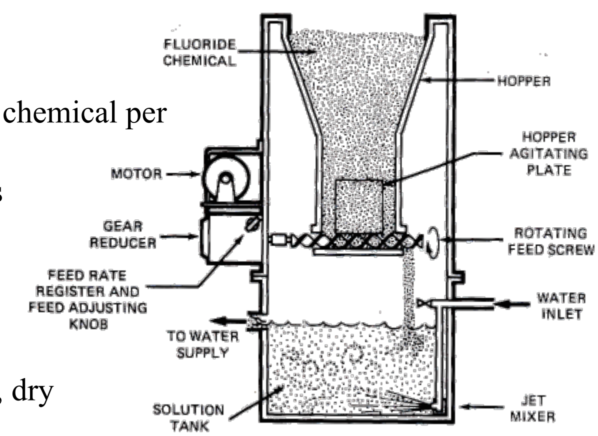
## Chlorine Gas Disinfection & Dechlorination System




**Chlorine gas application system**

# Chemical Feeders

## Dry feeders (granular/powder)




- **Volumetric dry feeders** deliver a *fixed volume* of chemical per rotation of an auger, belt, or vibratory tray.
- **Feed rate control:** Adjust auger speed → changes volume delivered per unit time.
- **Why operators use them:** Provides consistent dosing even if chemical density changes (humidity, storage conditions).
- **Common uses:** Lime, polymer powders, soda ash, dry chlorine products.

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# Liquid feed pumps (Bleach / Sodium Hypochlorite)

- **Metering assemblies & venturi systems:**
  - Use vacuum to pull chemical from storage into the feed line.
  - Provide steady, predictable dosing for hypochlorite solutions.
- **Dosing pumps:**
  - Peristaltic
  - Positive displacement
  - Proportional feed pumps (flow-paced)
- **Storage options:**
  - Bulk tanks, shuttle tanks, totes, drums
- **Backflow prevention:**
  - Spring-loaded check valves, vacuum breakers
- **Instrumentation:**
  - Rotameters for manual rate checks
  - Control panels for automatic pacing (flow, residual, or time-based)


# Gas Feed Systems (Chlorine, Sulfur Dioxide)

- **Solution feed systems:** Gas is pulled into a water stream to create a solution for dosing.
- **Pump output control:**
  - Stroke length (how far the plunger moves)
  - Stroke frequency (how fast it cycles)
- **Control options:**
  - Manual
  - Flow-paced (adjusts feed rate based on plant flow)
- **Pump types:**
  - Diaphragm
  - Peristaltic
  - Progressive cavity
- **Operator note:** Gas systems require leak checks, vacuum integrity, and emergency procedures.

# Chemical Feeders (O&M)

## Operation & Maintenance Requirements

- Daily / Routine Tasks:
  - Observe all operating components.
  - Inspect suction and discharge lines.
  - Check valves, diaphragms, rollers, fittings.
  - Replace worn tubing immediately.
  - Verify chemical strength (especially hypochlorite — it degrades).
  - Clean tanks and day tanks regularly.
- Calibration & Troubleshooting:
  - Calibrate chemical metering pumps routinely or whenever performance seems off.

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- Any leak in the system reduces chemical feed — repair immediately.
- If pump appears to run but feed rate drops → **suspect ruptured diaphragm**.
- Disassemble, clean, and inspect all wetted components per manufacturer recommendations.
- Maintain spare parts inventory

## Chemical Feeders (Safety & LOTO)

- Follow full LOTO procedures before servicing pumps, tanks, or feed lines.
- Maintain a spare parts inventory (tubing, diaphragms, rollers, check valves).
- Wear appropriate PPE for the chemical being handled (chlorine, hypochlorite, polymer, acids).
- Ensure chemical storage areas have ventilation, spill containment, and eyewash/shower access.
- Document all maintenance and calibration activities.
- Consult SDS and Hazardous Assessment and Emergency Procedures.
  - Review the Safety Data Sheet (SDS) for every chemical used (hypochlorite, polymer, acids, lime).
  - Complete hazard assessments before handling, mixing, or transferring chemicals.
  - Follow site-specific emergency procedures for spills, leaks, gas releases, or exposure.
  - Ensure eyewash, shower, ventilation, and PPE are available and functional.
  - Document all incidents and corrective actions.

# Calculations for Solution Chemicals

## Feed Pump Setting, % Stroke

***Formula:***

$$Feed\ Stroke\ \% = \left(\frac{Desired\ Flow,\ Q_d}{Maximum\ Flow,\ Q_m}\right) \times 100\%$$

***Example:***

The required chemical pumping rate has been calculated as 7.9 gpm. If the maximum pumping rate is 65 gpm, what should the percent stroke setting be?

? %Stroke; $Q_d$=7.9 gpm; $Q_m$=65 gpm

$$Feed\ Stroke\ \% = \left(\frac{Q_d}{Q_m}\right) \times 100\% \qquad = \frac{7.9}{65} \times 100\% = 0.1215 \times 100\% = \boxed{12.15\%}$$

## Feed Rates – Liquid Feed Rate mL/min

- To determine the settings for chemical feed pumps:
- First, use the standard pounds formula to find how many “dry pounds” are needed to obtain desired dosage.
- Then determine the "mL/min setting" for the feed pump.
- lbs/gal = 8.34 x s.g. x decimal assay
- gpd = lbs/day dry required ÷ lbs dry/gal
- mL/min = (gpd x 3,785) ÷ 1,440

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***Example problem:***

Plant flow = 24 MGD

Alum dosage required = 18 mg/L

Actual Alum assay = 48.9 % as $Al_2(SO_4)_3$

Alum solution s.g. = 1.27 g/mL

**Step One: Pounds @ 100%**

**24 MGD; 18 mg/L**

$$lbs/day = \text{MGD} \times 8.34 \times \text{mg/L} = 24 \times 8.34 \times 18 = \underline{3{,}603\ \text{lbs/day}}$$

**Step Two: Pounds in 1 gal**

**48.9 %; 1.27 g/mL**

$$\text{decimal assay} = \% \div 100 = 48.9 \div 100 = 0.489$$

$$lbs/gal = 8.34 \times \text{s.g.} \times \text{decimal assay} = 8.34 \times 1.27 \times 0.489 = \underline{5.179\ \text{lbs/gal}}$$

**Step Three: gpd to feed**

**3603 *lbs/day*; 5.179 *lbs/gal***

$$gpd = lbs/day \div lbs/gal = 3603 \div 5.179 = \underline{695.7\ \text{gpd}}$$

**Step Four: mL/min feed rate**

**3,785 mL/gal; 1440 min/day**

$$mL/min = (\text{gpd} \times 3785\ \text{mL/gal}) \div 1440\ \text{min/day}$$

$$\text{mL/min} = (695.7 \times 3785) \div 1440 = 2{,}633{,}224.5 \div 1440 = \boxed{1828.6\ \text{mL/min}}$$

***Condensed Solution Formula (mL/min)***

$$mL/min = \frac{\text{MGD} \times \text{mg/L} \times 2.628}{\text{s.g.} \times \text{assay}}$$

***Applied to long way:***

24 MGD; 18 mg/L; 48.9% as $Al_2(SO_4)_3$; 1.27 g/mL

$$\text{mL/min} = \frac{24 \times 18 \times 2.628}{1.27 \times 0.489} = \frac{1135\ \text{mL}}{0.6210\ \text{min}} = \boxed{1827.6\ \text{mL/min}}$$

***Example problem:***

A WWTP is treating a flow of 3.6 MGD. A 12% solution of Sodium Hypochlorite, having a s.g. of 1.18, is used for disinfection of this flow. A dosage of 4.4 mg/L will be applied. Find the mL/min feed pump setting:

? mL/min 3.6 MGD 12% Assay 1.18 s.g. 4.4 mg/L

$$mL/min = \frac{\text{MGD} \times \text{mg/L} \times 2.628}{\text{s.g.} \times \text{assay}}$$

$$\text{mL/min} = \frac{3.6 \times 4.4 \times 2.628}{1.18 \times 0.12} = \frac{41.63\ \text{mL}}{0.1416\ \text{min}} = 293.97\ \text{mL/min} = \boxed{294.0\ \text{mL/min}}$$

What would be the feed rate in gpm?

? gpm 294 mL/min 3,785 mL/gal

$$\frac{294\ \cancel{\text{mL}}}{1\ \text{min}} \times \frac{1\ \text{gal}}{3{,}785\ \cancel{\text{mL}}} = \frac{294\ gal}{3{,}785\ min} = 0.0777 = \boxed{0.078\ gpm}$$

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# Dry Chemical Feeders

- Dry chemical feeders (granular & powdered form) are calibrated to deliver in units of dry lbs/day.
- Use the same pounds formula to determine the lbs/day requirement.

$$lbs/day = MGD \times 8.34 \times mg/L$$

- Procedure for calibrating a dry feeder:
  1. Time how fast a bucket fills up (in minutes). Repeat at different settings (at least 5 times).
  2. Weigh after each fill up and record in a chart. Calculate lbs/day.
  3. Plot a calibration "curve" or line.

- After plotting lbs/day at several settings, the calibration curve should form a straight line.
- *A straight line indicates the feeder is delivering chemical consistently.*
- Crooked or scattered line = feeder is not feeding uniformly
- If the curve is **not** straight, adjust the auger, vibration, or feed mechanism per manufacturer instructions until linearity is achieved.
- **Most dry chemical feeders come with a manufacturer's feed-rate chart**, and it usually shows something like:
  - 25 percent setting = X lbs/day
  - 50 percent setting = Y lbs/day
  - 75 percent setting = Z lbs/day
  - 100 percent setting = max lbs/day
  - *Operators cannot trust that chart until you verify it with your own calibration*
  - This can be done in a spreadsheet program like MS Excel of Google Sheets automatically
  - A Blank worksheet is attached at the end.

***Example problem:***

A dry Alum feeder was tested, and the following data collected:

| | | |
|---|---|---|
| 20% | 480 g | 3 min |
| 40% | 1,000 g | 3 min |
| 60% | 1,490 g | 3 min |
| 80% | 1,980 g | 3 min |
| 100% | 2,470 g | 3 min |

## Calibration of Dry Feeders

| Setting% | Time (t) | g caught | g/hr* | lbs/day* |
|---|---|---|---|---|
| **100%** | 3 | 2470 | | |
| **80%** | 3 | 1980 | | |
| **60%** | 3 | 1490 | | |
| **40%** | 3 | 1000 | | |
| **20%** | 3 | 480 | | |

**Notes:* g/hr = g caught x 60 ÷ t lbs/day = g/hr x 24 ÷ 453.6

g/hr = g caught x 60 ÷ t

$$100\% = 2470\text{g} \times 60\ \text{min/hr} \div 3\ \text{min} = \boxed{49{,}400\ \text{g/hr}}$$

$$80\% = 1980\text{g} \times 60\ \text{min/hr} \div 3\ \text{min} = \boxed{39{,}600\ \text{g/hr}}$$

$$60\% = 1490\text{g} \times 60\ \text{min/hr} \div 3\ \text{min} = \boxed{29{,}800\ \text{g/hr}}$$

$$40\% = 1000\text{g} \times 60\ \text{min/hr} \div 3\ \text{min} = \boxed{20{,}000\ \text{g/hr}}$$

$$20\% = 480\text{g} \times 60\ \text{min/hr} \div 3\ \text{min} = \boxed{9{,}600\ \text{g/hr}}$$

# Calibration of Dry Feeders

| Setting% | Time (t) | g caught | g/hr* | lbs/day* |
|---|---|---|---|---|
| **100%** | 3 | 2470 | 49,400 | |
| **80%** | 3 | 1980 | 39,600 | |
| **60%** | 3 | 1490 | 29,800 | |
| **40%** | 3 | 1000 | 20,000 | |
| **20%** | 3 | 480 | 9,600 | |

**Notes:* g/hr = g caught x 60 ÷ t lbs/day = g/hr x 24 ÷ 453.6

lbs/day = g/hr x 24 hr/day ÷ 453.6 g/lb

$$100\% = 49{,}400 \times 24 \div 453.6 = \boxed{2614\ lbs/day}$$

$$80\% = 39{,}600 \times 24 \div 453.6 = \boxed{2095\ lbs/day}$$

$$60\% = 29{,}800 \times 24 \div 453.6 = \boxed{1577\ lbs/day}$$

$$40\% = 20{,}000 \times 24 \div 453.6 = \boxed{1058\ lbs/day}$$

$$20\% = 9{,}600 \times 24 \div 453.6 = \boxed{508\ lbs/day}$$

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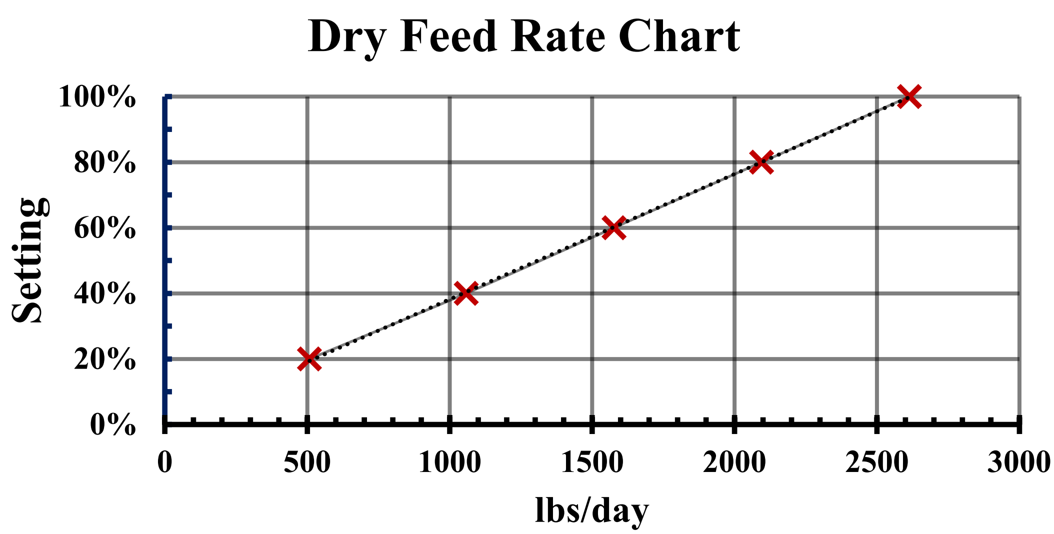
## Calibration of Dry Feeders

| Setting% | Time (t) | g caught | g/hr* | lbs/day* |
|---|---|---|---|---|
| **100%** | 3 | 2470 | 49,400 | 2614 |
| **80%** | 3 | 1980 | 39,600 | 2095 |
| **60%** | 3 | 1490 | 29,800 | 1577 |
| **40%** | 3 | 1000 | 20,000 | 1058 |
| **20%** | 3 | 480 | 9600 | 508 |

**Notes:* g/hr = g caught x 60 ÷ t lbs/day = g/hr x 24 ÷ 453.6

Now graph it:




# Fecal Sampling & Compliance

- Wastewater operators typically test for:
- Fecal Coliform
- E. Coli
- Sometimes Total Coliform depending on permit
- These are indicators of fecal contamination and tell you how well your disinfection process is working.
- Why Wastewater Systems Sample
  - Verify effluent disinfection is effective
  - Meet NPDES permit limits
  - Protect receiving waters
  - Detect treatment failures early
  - Adjust chlorine/UV dosing
  - This is compliance-driven, not distribution-driven.

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- Based on permit frequency, sampling is usually required:
  - Daily
  - Weekly
  - Monthly
- And also:
  - SSOs (Sanitary Sewer Overflows)
  - After major treatment upsets
  - When chlorine residual drops
  - When UV intensity drops
  - When turbidity spikes
  - When operators suspect contamination
- Fecal Indicator Methods
  - Membrane Filtration
  - Multiple-Tube Fermentation (MPN)
  - Colilert / DST

## Connects directly to:

- **Disinfection–Dechlorination**
  - Too little chlorine → fecal fails
  - Too much chlorine → dechlorination problems → false fecal pass
  - Poor mixing → inconsistent results
  - Too many UV bulbs out → fecal fails
  - Turbidity too high or algae bloom in UV channel → fecal fails
- **Mechanical Chemical Feeders**
  - Malfunctioning pumps →:
    - Low chlorine → fecal violations
    - Too much chlorine → dechlorination problems → false fecal pass
    - Dechlorination too low → false fecal pass
  - Plugged lines → no feed → instant failure
  - Air in lines → inconsistent dosing
  - Clogged or ‘stuck’ rotometers

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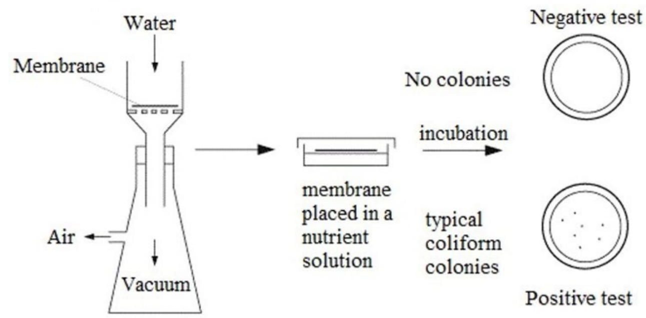
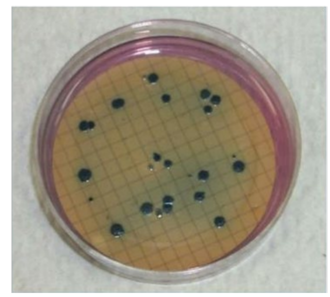
# Membrane Filtration (MF)

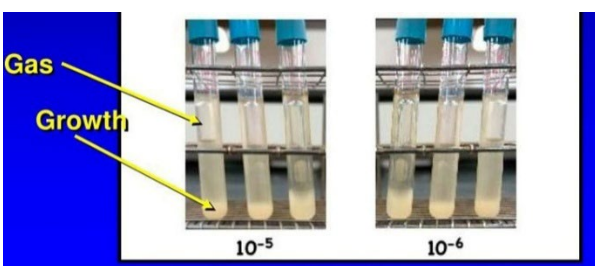



- **What it is:**
  - A measured volume of water is passed through a **0.45-micron membrane filter** that traps bacteria.
- **How it works:**
  - Filter is placed on selective growth media
  - Incubated at the required temperature
  - Colonies grow directly on the membrane
  - Operator counts colonies (CFU/100 mL)
- **Why operators need to know it:**
  - MF is fast, accurate, and widely used for wastewater effluent and drinking water compliance.



# Multiple-Tube Fermentation (MTF / MPN)

- **What it is:**
  - A statistical method using **multiple tubes** of growth media to estimate bacteria concentration.




- **How it works:**
- Sample is added to lactose broth tubes
- Tubes incubate
- Gas production = positive
- Pattern of positives is compared to an **MPN table**

- **Why operators need to know it:**
  - MTF is older but still accepted by EPA and ABC. It's used when water is turbid or has high solids.

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# Colilert / Defined Substrate Technology (DST)

- **What Colilert Is**
  - Colilert uses **defined substrates** that react with coliforms and E. coli, producing color and fluorescence in individual wells.
- **How It Works**
  - Add reagent to the sample
  - Pour into a **Quanti-Tray**
  - Seal the tray
  - Incubate for **24 hours**
  - **Yellow wells = Total Coliform**
  - **Fluorescent wells under UV = E. coli**
  - Count positive wells and compare to the **MPN table printed on the tray**
- **Why It's Used**
  - Fast and Simple
  - No membrane filters or multiple tubes
  - Works well for both drinking water and wastewater effluent
  - Approved by EPA for RTCR and NPDES fecal testing





# Fecal Sampling Procedures

- Grab samples **ONLY**
- Collect post-disinfection
  - Sample **after chlorine contact basin** or **after UV system**, depending on plant design.
- Sterile bottles with sodium thiosulfate
  - Prefer presterilized, disposable Whirl-pak® bags if using <u>**MF method**</u>
  - Sealed presterilized, disposable IDEXX/Colilert ™ bottles for <u>**DST method**</u>
- <u>*Why Thiosulfate?*</u>
  - Neutralizes chlorine so it doesn't kill bacteria in the bottle
  - Ensures accurate fecal count
- Leave headspace
  - Wastewater sampling **DOES allow headspace**.
  - "No headspace" is a **drinking water rule**.
  - Wastewater bottles are typically ¾ **full**.
- Avoid contamination
  - Gloves
  - Don't touch inside of bottle or lid
  - Don't sample from turbulent or splashing points
  - Avoid solids or debris if possible
  - Use a sampling pole if needed

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- Keep ≤ 10°C (on ice)
  - Store on ice immediately
  - Do **not** freeze
  - Maintain temperature until delivery
  - Samples that will take longer than 1 hour to analyze should be cooled to between 1˚ – 4˚ C on ice or in a refrigerator.
- Label & Fill out Chain of Custody (CoC):
  - Date
  - Time
  - Location (Sample point, effluent, post-UV, post-chlorination)
  - Sampler initials
  - Permit ID if required
- **Analyze within 6 hours**

## Common Sampling Mistakes

- These are the ones that cause permit violations:
  - Sampling too close to turbulence → solids get in the bottle
  - Sampling before full contact time
  - Forgetting thiosulfate bottles
  - Using non-sterile bottles or reusing Whirl-pak® bags
  - Letting samples warm up
  - Not mixing the sample gently before pouring into lab containers
  - Sampling during high chlorine demand events (storms, high flow)
  - Not documenting chlorine residual at the time of sampling
  - Not delivering to lab within 6 hours
- **What Happens When You Fail a Fecal Limit?**
  - Notify supervisor
  - Check chlorine residual or UV intensity
  - Inspect chlorine contact basin or UV channel
  - Check flow rate (high flow reduces contact time)
  - Check turbidity/solids
  - Adjust chlorine feed or UV output
  - Resample if allowed by permit

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Special Thanks to Timothy Crosswhite for photographs and charts & The King of Random for video links.

Presentations based off:

Chapter 10 Disinfection:
Wastewater System Operator's Manual
Ragsdale and Associates Training Specialists, LLC
https://www.nmwwa.org/_files/ugd/a8472e_ef77517d1bab42b08f7ae0f99d98005d.pdf

EPA Fact Sheets (September 1999):
Wastewater Technology Fact Sheet - Chlorine Disinfection; EPA 832-F-99-062
Wastewater Technology Fact Sheet - Ultraviolet Disinfection; EPA 832-F-99-064

Mountain Empire Community College; Lesson 22: Wastewater Disinfection

Texas AgriLife Extension Service Compliance and Test Reports with Fecal Sampling Information

TWUA Calculations Handbook

University of North Carolina at Chapel Hill; ENVR 412 – Ecological Microbiology

WEF.org OWWL - Wastewater Operations Fact Sheet - Disinfection

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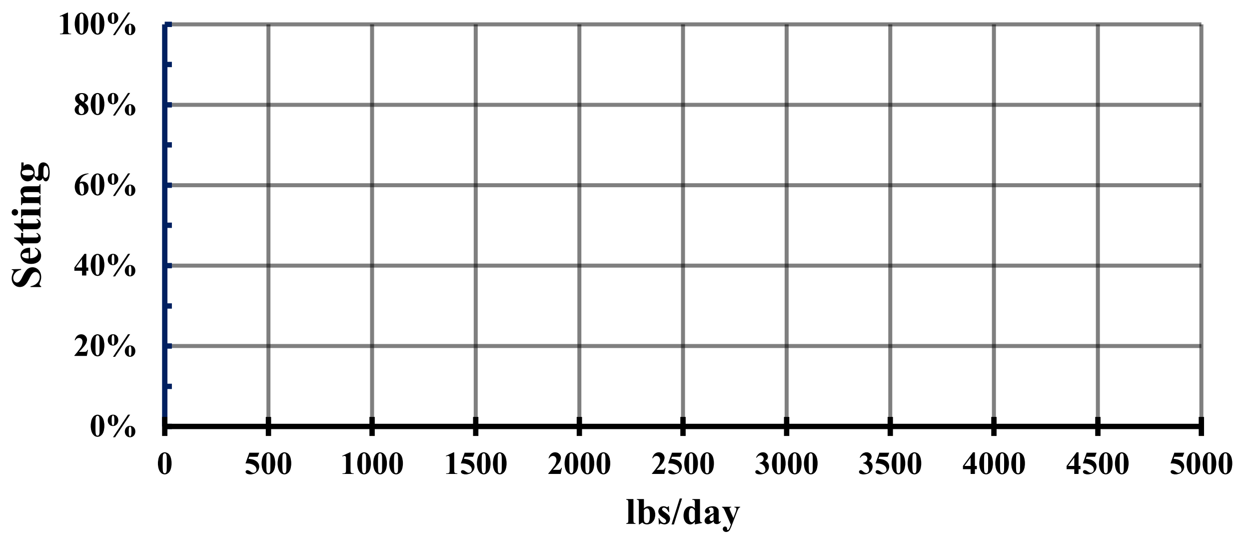
# Dry Chemical Feeder Calibration Worksheets

## Calibration of Dry Feeders

| Setting% | Time (t) | g caught | g/hr* | lbs/day* |
|---|---|---|---|---|
| 100% | | | | |
| 90% | | | | |
| 80% | | | | |
| 70% | | | | |
| 60% | | | | |
| 50% | | | | |
| 40% | | | | |
| 30% | | | | |
| 20% | | | | |
| 10% | | | | |

**Notes:* g/hr = g caught x 60 ÷ t lbs/day = g/hr x 24 ÷ 453.6

## Dry Feed Rate Chart



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# Practice Exam

Choose the best answer.

1. The outlet of a forced ventilation system for a chlorinator room should be located
   a. On the roof
   b. Above the window
   c. Near the floor
   d. At the same level with the blower

2. The fusible plug that is in all chlorine cylinders:
   a. Should be removed after the cylinder is emptied
   b. May be used as a top for the chlorine source
   c. Is used as an electrical connection for evaporating coils
   d. Should never be removed or tampered with

3. Three water borne diseases are:
   a. Mumps, measles, cold
   b. Scarlet fever, Pneumonia, hay fever
   c. Typhoid fever, dysentery, polio
   d. Tuberculosis, diphtheria, chickenpox

4. Ultra Violet Irradiation kills bacteria by:
   a. Heat
   b. Destroying their cellular genetic material
   c. Inhibiting their enzymatic system
   d. Splitting the cell in half

5. Chlorine applied minus ____________ equals chlorine residual.
   a. Chlorine dose
   b. Chlorine demand
   c. Chlorine residual
   d. Combined chlorine
   e. Free chlorine
   f. Total chlorine

6. Determine the chlorine demand of an effluent if the chlorine dose is 10 mg/l and the chlorine residual is 1.1 mg/L
   a. 8.9
   b. 1.0
   c. 9.1
   d. 11.1

7. What is the chlorination feed rate if the dosage is 12 mg/L for a flow of 2.0 MGD.
   a. 12 lbs/day
   b. 24 lbs/day
   c. 100 lbs/day
   d. 200 lbs/day

8. What does the term “pathogenic” means?
   a. Crazy gene
   b. Primary treatment process
   c. Disease-causing
   d. A cure

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9. The process of killing disease-causing organisms is called:
   a. homicide
   b. genocide
   c. suicide
   d. disinfection

10. Which is NOT a disinfection method?
    a. chlorination
    b. ozone
    c. ultraviolet light
    d. digestion

11. Which is a strong oxidizer?
    a. calcium hypochlorite
    b. exhausted carbon
    c. hydrogen sulfide
    d. carbon monoxide

12. Which is NOT a characteristic of chlorine gas?
    a. greenish-yellow color
    b. flammable
    c. 2.5 times heavier than air
    d. corrosive with moisture

13. What are the processes used to dechlorinate wastewater?
    a. holding ponds
    b. aeration
    c. sulfur dioxide and sulfite compounds
    d. carbon adsorption
    e. iron salts
    f. all of these

14. A sulphonator operates on the same principle as a:
    a. Chlorinator
    b. Positive-displacement pump
    c. Lime feeder
    d. Flocculator

15. Wastewater discharges must be disinfected to protect all of these except:
    a. Public Water Supplies
    b. Climate Change
    c. Recreational & Reuse receiving waters
    d. Aquatic and other wildlife

16. What is the optimum wavelength to effectively inactivate microorganisms when using UV?
    a. 100-280 nm
    b. 254 nm
    c. 250-270 nm
    d. 380-750 nm

17. Which condition reduces the effectiveness of UV disinfection?
    a. Low turbidity
    b. High turbidity
    c. Clear water
    d. pH

18. Sterilization kills all microorganisms.
    a. True
    b. False

19. How many pounds of calcium hypochlorite are needed to treat 29.5 MGD with a 2.1 mg/L dosage if the calcium hypochlorite ($Ca(OCl)_2$) has 70% available chlorine?
    a. 517 lbs/day
    b. 7.38 lbs/day

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c. 738 lbs/day
d. 680 lbs/day

20. Which disinfection method is not affected by temperature or pH?
    a. Chlorine
    b. Ozone
    c. Chlorine Dioxide
    d. UV

21. What can be used to locate small chlorine gas leaks?
    a. carbon monoxide fumes
    b. hairspray fumes
    c. ammonia fumes
    d. water vapor

22. What two test methods produce a color change of pink and blue when testing for residuals?
    a. DPD and Indigo
    b. pH and Temperature
    c. DPD and pH
    d. Temperature and Indigo
    e. Indigo and pH
    f. Temperature and DPD

23. Chlorine combines with ammonia in wastewater to form:
    a. trichloronitrogen
    b. trihalomethanes
    c. chloramines
    d. dichlorous acid

24. If a chlorine dosage of 12 mg/L is added to a wastewater effluent containing ammonia and the chlorine demand is 11.5 mg/L, the residual would be
    a. sufficient
    b. 0.5 mg/L
    c. a monochloramine
    d. b and c

25. UV disinfection increases chlorine residual in the effluent.
    a. True
    b. False

26. Which is not part of a UV disinfection system?
    a. Bulbs
    b. Underdrain
    c. Ballasts
    d. Racks
    e. Baffles
    f. Quartz Sleeves

27. A small treatment plant produces an effluent with a pH of 7, a TSS value of 20 mg/L and a chlorine residual of 13 mg/L. Regulations specify, under those conditions, that a minimum dose of 10 mg/L is required. If the WWTP uses a dual tablet delivery system and a chlorine tablet delivers a dose of 9 mg/L, what was the chlorine demand?
    a. 19 mg/L
    b. 23 mg/L
    c. 4 mg/L
    d. 5 mg/L
28. A CT value of 6 mg-min/L is the value that is commonly used to confirm that good disinfection is occurring. How many minutes and seconds must the above effluent be in contact with tablets?
    a. 0 min 28 sec
    b. 0 min 46 sec
    c. 27 min 6 sec
    d. 4 min 6 sec

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29. Why is overdosing for chemical dechlorination a problem?
    a. pH is lowered below 6.0-8.0 normal range
    b. DO falls below minimum 4.0 mg/L
    c. There is no problem
    d. Raises the temperature of the effluent
    e. a and b
    f. a and d

30. Combined, or chemically bound, chlorine residuals are composed of:
    a. Free chlorine
    b. Ammonia
    c. Chloramines
    d. All of the above

31. What value must the total suspended solids (TSS) be below for effective UV disinfection?
    a. 20 mg/L
    b. 30 mg/L
    c. 25 mg/L
    d. 50 mg/L

32. ______________ and ______________ must be worn when servicing or working near energized UV bulbs/banks.
    a. A respirator, goggles
    b. A hard hat, gloves
    c. Safety glasses, sunscreen
    d. An SCBA, a chemical suit

33. The amount of chlorine that is added to the waste stream until the chlorine demand has been satisfied, and further additions of chlorine will result in a free chlorine residual that is directly proportional to the amount of chlorine added beyond that point is called:
    a. Chlorine Demand
    b. Chlorine Residual
    c. Combined Chlorine
    d. Breakpoint Chlorine

34. UV radiation is generated by passing energy through _____________ vapor.
    a. Mercury
    b. Air
    c. Neon
    d. Smoke

35. Why do wastewater systems perform fecal sampling?
    a. Verify effluent disinfection is effective
    b. Meet NPDES permit limits
    c. Protect receiving waters
    d. Detect treatment failures early
    e. Adjust chlorine/UV dosing
    f. All of these

36. Freezing will occur if chlorine gas is drawn off too quickly. 150 mg/L cylinders have a draw rate of _______ lbs/day and 1 ton cylinders have a draw rate of _________ lbs/day.
    a. 42/9600 lbs/day
    b. 40/400 lbs/day
    c. 100/1000 lbs/day
    d. 150/1500 lbs/day

37. Which type of chloramine is the strongest disinfectant?
    a. Monochloramine
    b. Trihalomethanes

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c. Dichloramine
d. Trichloramine

38. Some microorganisms, like cryptosporidium, can repair the damage and reactivate after UV disinfection.
a. True
b. False

39. Cartridge full face gas masks, supplied air full face mask respirators and SCBAs are required safety equipment for which disinfection methods:
a. Chlorination
b. UV Radiation
c. Step-aeration
d. None of the above

40. Sulfur Dioxide ($SO_2$) gas used for dechlorination is:
a. Non-flammable
b. Colorless gas
c. Pungent Odor
d. Irritant
e. Corrosive
f. All of these

41. __________________ for natural dechlorination is part of effluent polishing in the tertiary treatment process often found in rapid sand filters.
a. Sand
b. Granular Activated Carbon (GAC)
c. Gravel
d. Peat moss

42. Coliform testing is required on most permits for POTW who discharge into bodies of water as a way to check for proper disinfection. Coliforms are measured in MPN/100 mL and :
a. CFUs/100 mL
b. mg/L
c. lbs/day
d. cfs

43. When chlorine breaks down in water it forms which 2 acids?
a. hypochlorous acid (HOCl) & hydrochloric acid (HCl)
b. hypochlorous acid (HOCl) & acetic acid ($C_2H_4O_2$)
c. hydrochloric acid (HCl) & sulfuric acid ($H_2SO_4$)
d. acetic acid ($C_2H_4O_2$) & sulfuric acid ($H_2SO_4$)

44. Chlorine gas cylinders should be stored in direct sunlight to prevent frosting.
a. True
b. False

45. Sulfur dioxide gas is administered as a 5:1 ratio when used in dechlorination.
a. True
b. False

46. The effectiveness of chlorine disinfection depends on the product of chlorine concentration and contact time, known as:
a. C×T
b. Contact chamber rating
c. CT value
d. Chlorine demand

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47. Which factor increases chlorine demand in wastewater?
    a. Organic matter and ammonia
    b. High UV transmittance
    c. Low turbidity
    d. Clean effluent

48. Which chlorine residual includes both free and combined chlorine?
    a. Free Chlorine Residual (FCR)
    b. Combined Chlorine Residual (CCR)
    c. Breakpoint residual
    d. Total Chlorine Residual (TCR)

49. A ruptured diaphragm in a chemical metering pump will cause:
    a. Increased feed rate
    b. No change in feed rate
    c. Decreased chemical feed
    d. Higher chlorine residual

50. Dry chemical feeders deliver chemical based on:
    a. Weight of chemical
    b. Volume per rotation
    c. Pressure in the hopper
    d. Temperature of the chemical

51. A crooked or scattered calibration curve for a dry chemical feeder indicates:
    a. The feeder is not feeding uniformly
    b. The chemical is too strong
    c. The pump stroke is too high
    d. The feeder is delivering chemical consistently

52. Which pump type is commonly used for sodium hypochlorite feed systems?
    a. Jet pump
    b. Submersible pump
    c. Centrifugal pump
    d. Peristaltic pump

53. Before servicing chemical feed systems, operators must follow:
    a. Breakpoint chlorination
    b. Lock Out/Tag Out
    c. UV intensity checks
    d. CT calculations

54. A WWTP is treating a flow of 1.2 MGD. A 10% solution of Sodium Hypochlorite, having a specific gravity of 1.11 is used for disinfection of this flow. A dosage of 5.8 mg/L will be applied. Find the mL/min feed pump setting.
    a. 16.5 mL/min
    b. 18.3 mL/min
    c. 165 mL/min
    d. 523 mL/min

55. The required chemical pumping rate has been calculated as 6.5 gpm. If the maximum pumping rate is 35 gpm, what should the percent stroke setting be?
    a. 19%
    b. 12%
    c. 54%
    d. 5%

56. Gas feed systems (chlorine, sulfur dioxide) control feed rate by adjusting:
    a. Water temperature
    b. Stroke length and stroke frequency

 

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c. UV transmittance
d. Turbidity

57. Fecal coliform sampling is used to verify that effluent disinfection is effective.
    a. True
    b. False

58. Which method is used for fecal coliform testing?
    a. Hardness titration
    b. Nephelometric turbidity
    c. Jar testing
    d. Membrane Filtration

59. Total residual chlorine sampling and fecal sampling must be ___________ samples, not ____________ samples.
    a. grab, mixed
    b. mixed, composite
    c. grab, composite
    d. composite, grab

60. A WWTP is treating a flow of 4.8 MGD. The feed rate is calculated at 7900 mL/min. What would be the feed rate in gpm?
    a. 0.21 gpm
    b. 2.1 gpm
    c. 100 gpm
    d. 210 gpm

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# Answers

1. c
2. d
3. c
4. b
5. b
6. a 8.9 mg/L

Residual = Dose – Demand
10.0 mg/L – 1.1 mg/L = 8.9 mg/L

7. d 200 lbs/day

$$lbs/day = MGD \times mg/L \times 8.34$$
$$= 2 \times 12 \times 8.34$$
$$= 200.16\ lbs/day$$

8. c
9. d
10. d
11. a
12. b
13. f
14. a
15. b
16. c
17. b
18. a
19. c 738 lbs/day

$$lbs/day = \frac{MGD \times mg/L \times 8.34}{dec.assay}$$
$$= \frac{29.5 \times 2.1 \times 8.34}{0.70}$$
$$= \frac{516.7}{0.70} = 738\ lbs/day$$

20. d
21. c
22. a
23. c
24. d
25. b
26. b
27. d 5 mg/L

Dose = 9 mg/L x 2 = 18 mg/L
Demand = Dose – Residual
18 mg/L – 13 mg/L = 5 mg/L

28. a 0 min 28 sec

$$Time = CT \div Conc.$$
$$= 6\ mg \cdot min/L \div 13\ mg/L = 0.4615\ min$$
$$0.4615\ min \times 60\ sec/min = 27.69\ sec$$

29. e
30. d
31. b
32. c
33. d
34. a
35. f
36. b
37. c
38. a
39. a
40. f
41. b
42. a
43. a
44. b
45. b
46. c
47. a
48. d
49. c
50. b
51. a
52. d
53. b
54. c 165 mL/min

$$mL/min = \frac{\text{MGD} \times \text{mg/L} \times 2.628}{\text{s.g.} \times \text{assay}}$$
$$\text{mL/min} = \frac{1.2 \times 5.8 \times 2.628}{1.11 \times 0.10}$$
$$= \frac{18.29\text{ mL}}{0.111\text{ min}}$$
$$= 165\ \text{mL/min}$$

55. a 12%

$$Feed\ Stroke\ \% = \left(\frac{Q_d}{Q_m}\right) \times 100\%$$
$$= \frac{6.5}{35} \times 100\%$$
$$= 0.1857 \times 100\%$$
$$= 19\%$$

56. b
57. a
58. d
59. c
60. b 2.1 gpm

$$= \frac{7{,}900\ gal}{3{,}785\ min} = 2.1\ gpm$$