Chlorination and Disinfection

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Disinfection and Sterilization

- **Disinfection** – inactivates pathogenic organisms
- **Sterilization** - destroys all organisms

"To all Citizens: boil and strain the water before drinking to prevent hoarseness."

Hippocrates, 350 B.C.

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Purpose of Disinfection

Disease producing organisms are commonly called: Pathogens

- Destroy harmful organisms
- Protect the public from disease-causing pathogens by **inactivating** pathogens to ensure that they are reduced to non-harmful levels
- The measure used to determine the effectiveness of disinfection is the coliform group; means pathogenic bacteria may be present.

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Coliform Group of Bacteria

Includes all the aerobic and facultative anaerobic gram-negative, nonspore-forming, rod-shaped bacteria that ferment lactose (a sugar) within 48 hours at 35 °C (human body temperature).

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Considerations for Choosing a Disinfectant

- Effective for the Conditions Encountered
- Economical
- Operationally practical
- Reliable
- Safe for public consumption with no unintended consequences

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Disinfection Agents

- Heat energy
- Radiant energy – UV
- Chemical Agents

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Disinfection by Heat

- Expensive to operate on large scale
- Used for emergency situations in distribution systems
- Precautionary Boil Water Notices are issued when the distribution system is compromised
- Clearance requires two consecutive days of negative coliform samples

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Disinfection by Radiant Energy (Ultraviolet Radiation)

- Ultraviolet Radiation (UV) used selectively in surface water treatment plant applications
- No residual activity so chlorine is used as secondary disinfectant
- Inactivation of cycts (Giardia) and oocyts (Crypto) difficult to measure
- Very Susceptible to turbidity

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Disinfection by Chemical Agents in the U.S.

- Chlorine and Monochloramine 93%
- Potassium Permanganate 5%
  (Used as alternate oxidant w/ Cl_2 secondary)
- Ozone (O_3) 1%
  (requires secondary disinfectant)
- Chlorine Dioxide 1%
  (requires secondary disinfectant)
- Hydrogen Peroxide < 1%
  (requires secondary disinfectant)

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Reasons for the Selection of Chlorine as a Disinfectant

- Readily available and economical
- Low cost compared to other substances
- Proven effectiveness in relatively low dosages
- Simple feed and control procedures
- Requires safe storage and handling

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Disadvantages in the Use of Chlorine

- Highly toxic
- Regulatory agencies placing tightening restrictions on storage and use
- Must have Emergency Response Plan
- Produces Disinfection Byproducts

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Other Uses of Chlorine at a Water Treatment Plant

- Control Aquatic Life
- Oxidize Iron, Manganese and Sulfides
- Remove Tastes and Odors
- Maintain a Microbial Residual in Water Distribution System
- Prevent Algal Growth in Basins and Plant Process Facilities
- Improve Coagulation and Filtration

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Use of Chlorine for Removing Taste and Odors

- Most widely used chemical for color removal
- Effective for use for organic odors such as fishy, grassy or flowery
- Very effective for removing (oxidizing) inorganics such as iron or hydrogen sulfide
- Will intensify phenolic (solvent) odors
- Will increase THM's and HAA5's
- Alternatives include Potassium Permanganate, Ozone and Chlorine Dioxide

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Use of Potassium or Sodium Permanganate as Disinfectant

- Powerful Oxidizing Agent
- Used to Remove Fe/Mn and TOC
- Does not produce DBPs
- Shipped as a Solid (KMnO4) or Liquid (NaMnO4)
- Two to three times as expensive as Cl
- Corrosive, stains purple and can color water pink (removed with chlorine).
- Requires Secondary Disinfectant

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Use of Ozone (O_3) as a Disinfectant

- Effective in taste in odor removal. Does not produce TTHMs or DBP
- Bromate, MCL must be controlled
- No residual, so secondary disinfectant required
- Requires on-site generation
- Unstable - not stored
- Utilizes sensitive equipment which requires careful monitoring

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On-site Ozone Generation

Ozone is always generated on-site. Dosing is accomplished in chamber, any residual Ozone is purged and secondary disinfectant is added.

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Chlorine Dioxide

- Long been used for taste and odor and for iron and manganese control.
- Will not produce THMs and HAA5s.
- Can produce chlorite and chlorate residuals in drinking water. Chlorate has an established MCL.
- Must be prepared on-site and uses gas chlorination system to produce feed product.
- It is hazardous and can cause suffocation due to lack of oxygen.
- It is odorless, colorless, and will accumulate at lowest level because it is heavier than air.

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Chloramines

- Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia
- Used as an alternative disinfectant but is less effective as a disinfectant than free chlorine residual
- Its use dependent on raw water quality
- Effective in accomplishing these objectives:
  - Reducing formation of THMs and DBPs
  - Maintaining residual in distribution system
  - Penetrating the biofilm and reducing the potential for coliform regrowth.
  - Killing or inactivating HETEROTROPHIC plate count bacteria
  - Reducing taste and odor problems

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Methods of Producing Chloramines

- Preammoniation followed by later chlorination (produces less THMs with no phenolic tastes and odor)
- Concurrent addition of chlorine and ammonia (produces the lowest amount of THMs)
- Prechlorination/Postammoniation (will result in formation of more THMs)

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Use of Chlorine

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Forms of Chlorine

- Gas Chlorine (Cl_2) - 100% available as chlorine
- Liquid Chlorine or Bleach (NaOCL) - Sodium hypochlorite (5% - 15% active chlorine) is a pale yellow liquid
- Solid Chlorine [$Ca(OCL)_2$] - Calcium hypochlorite comes in a granular, powdered or tablet form. It is a white solid that contains 65% to 75% available chlorine.

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Gas Chlorine

- Lowers the pH of the water
- Produced from liquid chlorine shipped in pressurized cylinders
- 100% available as chlorine
- Moisture in a chlorination system will combine with the chlorine gas and cause corrosion

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Liquid Chlorine
(Sodium Hypochlorite)

- Liquid chlorine raises the pH of the water
- Arrives in a plastic container
- 5 -15% chlorine by weight
- More expensive than converting chlorine in liquid form to gas
- Safe and easy to handle and dose
- Very corrosive
- Toxic - apply in vented area
- Weakens over time

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Solid Chlorine
(Calcium hypochlorite)

- Solid chlorine raises the pH of the water
- 65% to 75% available chlorine
- Easily dissolves in water
- Easy to store; longer shelf life than liquid
- Very corrosive
- Highly reactive
- Toxic - apply in vented area
- Undissolved solids can foul check valves and plug injection fittings

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Factors Affecting Chlorination Effectiveness

- Chlorine concentration (higher increases effectiveness)
- Form (gas lowers pH, more effective)
- Effluent pH (lower increases effectiveness)
- Effluent temperature (higher increases effectiveness)
- Contact time (generally, longer increases effectiveness)
- Effluent suspended solids (turbidity reduces effectiveness)

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Chlorine Residual Requirements in Distribution System

A chlorine residual of 0.20 mg/l means that the amount of chlorine in the water is

0.20 pounds of chlorine per 1 million pounds of water

A free chlorine residual of 0.20 mg/l or a combined chlorine residual of 0.60 mg/l or an equivalent chlorine dioxide residual, must be maintained in the water distribution system at all times.

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Relationship between HOCl, OCl- and pH

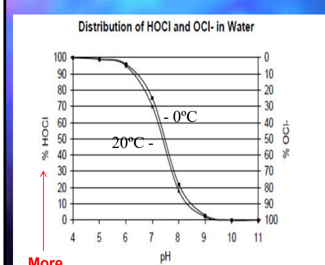

Figure 24.2 Distribution of HOCl and OCl- in water

- Chlorine reacts with water producing hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-)
- Both provide the disinfection ability of chlorine
- Chlorine gas tends to lower pH
- Hypochlorite compounds tend to raise the pH
  - $Ca(OCl)_2$ ~ pH 7-8
  - NaOCl ~ pH 13

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Breakpoint Chlorination

Breakpoint chlorination is the process of adding chlorine to water until the chlorine demand has been satisfied.

- Further additions of chlorine will result in a chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint
- Public water supplies are normally chlorinated PAST THE BREAKPOINT.

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Reactions of Chlorine with Water Constituents

Order of Reaction

1. Reducing agents (inorganics)
   (hydrogen sulfide (H_2S), ferrous ion (Fe^{2+}), manganous ion (Mn^{2+}), and nitrite ion (NO_2^-)
2. Reducing agents (organics and ammonia)
   Chloramines and chlororganics will form
3. Chlororganics and chloramines partly destroyed
4. Breakpoint - Free available residual formed (some chlororganics remain)
5. Process is called “Breakpoint Chlorination”

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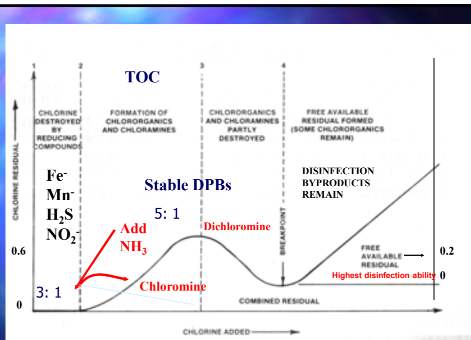

Breakpoint Chlorination Curve

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Substances that Cause Chlorine Demand (mg/l to mg/l basis)

- Hydrogen Sulfide (H_2S) (8:1 ratio)
- Inorganic metals - Fe and Mn (0.67:1 ratio)
- Nitrite (5:1 ratio, 3:1 ratio with NH_3)
- Organic materials (TOC and NOM), (0.1:1 ratio)
- All react with chlorine and reduce it to the chloride ion which has no disinfectant power
- H_2S > 0.3 mg/l and Fe > 0.1 mg/l must be filtered to remove colloidal solids

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Process Calculations

- Two process calculations
  - Chlorine dosage, mg/l
  - Chlorine demand, mg/l
- To calculate dose use feed rate formula or use Davidson's Pie

$$\text{Chemical feed, lbs/day} = \frac{(\text{Chlorine Dose, mg/l})(\text{Flow, MGD})(8.34\text{ lbs/gal})}{(\text{Purity, decimal})}$$

$$\text{Chlorine Dose, mg/l} = \frac{(\text{Chemical feed, lbs/day})(\text{Purity, decimal})}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

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Example: A chlorinator is set to feed 15 pounds of chlorine in 12 hours to a flow of 0.95 MGD. Find the chlorine dose in mg/l.

$$\text{Chlorine Dose, mg/l} = \frac{(\text{Chemical feed, lbs/day})(\text{Purity, decimal})}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

$$\text{Chlorine Dose, mg/l} = \frac{30\text{ lbs Cl/day}}{(0.95\text{ MGD})(8.34\text{ lbs/gal})}$$

Chlorine Dose, mg/l = 3.8 lbs Cl/million lbs of water

or = 3.8 ppm or 3.8 mg/l

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Chlorine Relationships

CL Dose = Chlorine Residual + CL Demand

Chlorine Residual = CL Dose - CL Demand

CL Demand = CL Dose - Chlorine Residual

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Determine the chlorine demand in mg/l for our previous example if the chlorine residual after 30 minutes of contact time is 1.0 mg/l.

Chlorine Demand = CL Dose - CL Residual

Chlorine Demand = 3.8 mg/l – 1.0 mg/l

Chlorine Demand = 2.8 mg/l

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Inactivation of Bacteria and Virus with Chlorine

- Inactivation of Pathogens is accomplished by meeting CT limits
  (Time that Pathogen is in contact with concentration of residual chlorine)
- 3-Log Giardia Inactivation for SW 99.9%
- 4-Log Virus Inactivation for GW 99.99%
- Tables of acceptable Inactivation (mg-min/l) are published by DEP

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Chlorine Residual

- Free Chlorine - aqueous chlorine, hypochlorite ion and hypochlorous acid
- Combined Chlorine Residual - compounds formed by reactions of hypochlorous acid and ammonia (chloramines)
- Total Chlorine Residual - sum of free and combined chlorine

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Minimum Chlorine Residual

- DEP requirements are 0.20 PPM Free Chlorine Residual or 0.60 PPM Chloramine Residual at all points in Distribution System

The most probable cause of the coliform count failing to meet regulatory standards is?

A low chlorine residual

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Considerations for Hypochlorination Systems

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Difference between Gas and Hypochlorination

- Gas chlorine lowers the pH (increases the hydrogen concentration) favoring the formation of Hypochlorous acid (more effective)
- Hypochlorination (both Sodium and Calcium) raises the pH favoring the formation of the Hypochlorite ion. (less effective)

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Parts of a Hypochlorinator

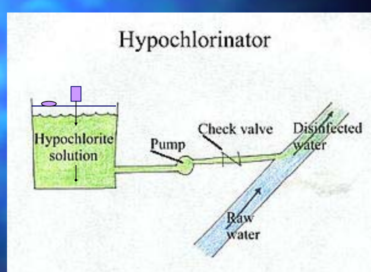
Parts:

Mixing Tank

Metering Pump

Check Valve

Well Pump



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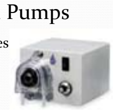
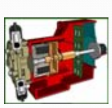
Chemical Feed Pumps

2 Basic Types




- Peristaltic (tube or hose)
- Diaphragm (solenoid, Motor or Hydraulic)

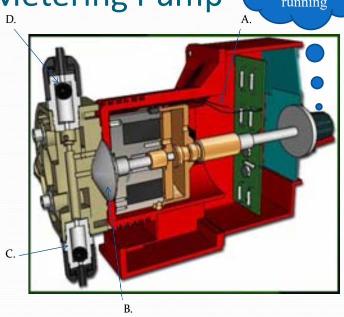


Parameter	Peristaltic Pump	Diaphragm Pump
Fluid		
Chemical resistance	- Fewer components to be attacked. Few pump tube material options.	- Many components to be attacked. Many component material options.
Un-dissolved solids	- Excellent: no valves to clog.	- Poor: valves can clog causing failures.
Outgassing	- Excellent: automatically primes	- Poor: difficult to prime
Shear stress	- Excellent: will not damage fluid	- Poor: can damage delicate fluid
Temperature	- Limited range: pump tubing is affected by high and low temperatures.	- Extended range: effect of temperature on the diaphragm is minimal.
Pressure		
Injection Pressure	- Limited discharge range - <125psi typical. No change in output due to changes in system pressures.	- Extended discharge range - >125psi typical. Large change in output due to changes in system pressure.
Control		
Remote Adjustment	- Excellent: steady dispersion of chemical at very low output with speed adjustment.	- Good: intermittent dispersion of chemical at low outputs.
External communications	- Excellent	- Excellent
Diagnostics	- Excellent: tube failure and flow verification alarm systems available.	- Excellent: diaphragm failure and flow verification alarm systems available.
Maintenance		
Service interval	- Service required at regular intervals.	- Service recommended at regular intervals.
Life expectancy	- Excellent	- Excellent

Diaphragm Metering Pump

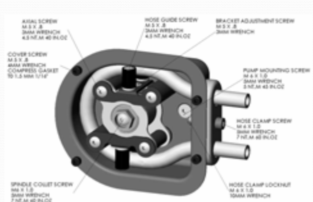
Change stroke length only when running

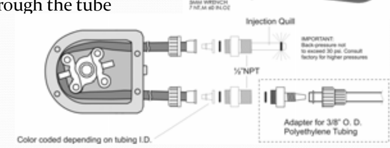
A. The coil is energized via electrical charge on the board
B. The solenoid shaft pushes the diaphragm into the pump head cavity
C. The suction ball valve seats (via gravity)
D. Liquid in the pump head is forced out through the discharge valve as the ball is forced to raise in the guide



Peristaltic Metering Pump

- A motor drives a shaft that is connected to rollers
- The rollers push the tubing flat against the collet which drives the liquid through the tube

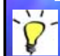




Hypochlorination System Maintenance Considerations

Cl lines are what color? YELLOW

- Scale has a tendency to form in pumps, feed lines, and injection points
- Regularly inspect and clean pumps, poppet valves, and injector points. If this is not done, scale will prevent the pump from moving solution into the water to be disinfected. Monitoring chlorine residuals may point to needed pump maintenance.



- Clean by pumping a mild acid (HCL) solution through system.
- Pump should be properly lubricated and free of corrosion
- Adjust feed rate only when running
- Do not store chemical for long periods

@ Date of Manf. 12.5% after 30 days 11.5%

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Considerations for Hypochlorite Storage

- Protect skin, eyes, and respiratory tract
- Wear protective gloves Hypochlorite will burn skin
- Cover all containers
- Keep chemical dry, covered and stored away from direct sunlight.
- Add water to container before the hypochlorite is added to avoid splashing of acid.

- Flush all spills with large amounts of water
- Keep the chlorine room well ventilated.
- Store Calcium hypochlorite away from contact with organic matter to prevent fire.

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Considerations for Gas Chlorination Systems

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Physical and Chemical Properties of Chlorine as a Gas

- Pressurized liquid expands 450 times in atmosphere
- Under normal atmospheric pressure at room temperature, chlorine is a yellow-green gas
- 2.5 times heavier than air

Exhaust fans should be located where?
Floor level.

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Maximum Draw-Off Rates

150 lb cylinders - approximately 40 lbs/day
1-ton containers - approximately 400 lbs/day
Computed as 8 pounds / F° drop

- Temperature of remaining chlorine decreases as the rate of withdrawal increases
- When temperature of chlorine is low enough it will not evaporate

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Preventing Chlorine Icing

- When attempting to feed more than the allowable amount from any container, manifolding is required

Computed as 8 pounds / F° drop

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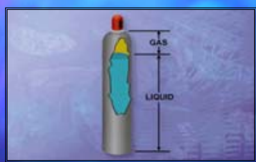
Dosing Configurations of Chlorine Cylinders



150 lbs Cl - 92 lbs Tare
Total Weight ~ 242 lbs

2000 lbs Cl – 1550 lbs Tare
Total Weight ~ 3,600 lbs

When exposed to heat gas inside tank will expand and could easily rupture a cylinder. For this reason cylinders are not filled to more than 85% of their volume.

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Storage of Chlorine Cylinders

- Keep away from heat or direct sunlight.
- Provide separate room with ventilation.
- Maintain temperature above 50°F to prevent icing.
- Protect from Fire
- Never store near turpentine, ether, anhydrous ammonia, hydrocarbons or other materials that will react violently with chlorine.

- Chlorine tanks are provided with fusible plugs that melt between 158 to 165 degrees F.
- Ton cylinders will have 6 to 8 of these plugs, 3 or 4 on each end; 150 lb, one below the valve seat.

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Safe Handling of 1-Ton Cylinder

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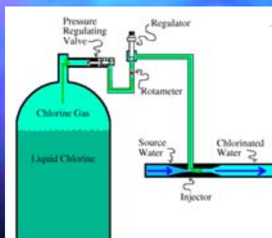
Principles of Gas Chlorination

Feed pump is not pumping what is the problem?

Vacuum leak



Primary advantage of vacuum operation is safety. If there is a break in vacuum the chlorinator stops the flow of chlorine.

- Pressure Regulating Valve - maintains proper operating pressure
- Rotameter – indicates the rate of flow
- Regulator – used to adjust the CL feed rate
- Injector – injects gas into flow stream

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Disinfection Troubleshooting

Symptom	Cause
Increase in coliform level	Low chlorine residual
Drop in chlorine level	Increase in chlorine demand; Drop in chlorine feed rate

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- Question: A plant uses 647 chlorine containers in a year. The average withdrawal from each is 138 pounds. What is the total number of pounds used for the year?

  a. 89,286 lb
  b. 28,487 lb
  c. 89,875 lb
  d. 69,876 lb

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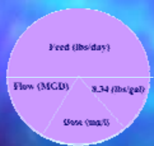
Find the Chlorine Dose



A chlorinator is set to feed 20lbs of chlorine in 12 hrs to a flow of 0.85 MGD. Find the chlorine dose in mg/l.

Dose = Feed/(flow x 8.34)

Check units

$$\text{Feed} = \frac{20\text{lbs}}{12\cancel{\text{hrs}}} \times \frac{24\cancel{\text{hrs}}}{1\text{ day}} = \frac{40\text{lbs}}{\text{day}}$$

$$\text{Dose} = \frac{40\cancel{\text{lbs}}}{\cancel{\text{day}}} \times \frac{\cancel{\text{day}}}{0.85\text{ M}\cancel{\text{Gal}}} \times \frac{\cancel{\text{gal}}}{8.34\cancel{\text{lbs}}}$$

Dose = 5.6 ppm or 5.6 mg/l

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Chlorine Safety

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All Forms of Chlorine are Hazardous

- Chlorine gas/liquid - extremely hazardous substance
- Calcium hypochlorite and sodium hypochlorite - hazardous substance
- Disinfection agents kill living organisms and tissue

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Chlorinator Start Up

- Use Self Contained Breathing Apparatus, Protective Clothing and work in pairs
- Inspect cylinder before connecting
- Check fittings
- Use new lead gasket
- Connect yoke with ¾ turn
- Open cylinder valve one turn
- Check for leaks with ammonia (rag preferable)
- Have emergency repair equipment on-hand (A-kit 150, B-kit 2000, C-kit tank car)

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Chlorine Leaks

- Inspect for leaks by placing an ammonia - soaked rag near each valve and joint.
- A polyethylene "squeeze bottle" filled with ammonia water to dispense ammonia vapor may also be used.
- Avoid spraying ammonia water on any leak or touching the soaked cloth to any metal (will form acid).
- The formation of a white cloud of vapor will indicate a chlorine leak .

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Emergency Eyewash Shower at Small Plant

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Effects of Chlorine on Humans

If a victim of chlorine gas contact has throat irritation, what liquid will help to reduce the irritation?

MILK

Chlorine Conc	Physiological Response
0.3-3.5 mg/L	detectable by smell & devices
5 mg/L	noxiousness
15 mg/L	throat irritation
30 mg/L	causes coughing
40-60 mg/L	damage to tissue
1000 mg/L	death after a few breaths

- Permissible Exposure Level (PEL) is 0.5 ppm (8-hour weighted average)
- Immediately Dangerous to Life or Health (IDLH) concentration is 10 ppm

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Contents of a Chlorine Emergency Preparedness Program

- Chlorine Safety Program
- Written Rules and Safety Procedures
- Periodic hand-on training
- Establishment of Emergency Procedures
- Establishment of Maintenance and Calibration Program
- Fire, Police, Emergency Agency Coordination and (Chemtrec 800-424-9300.)

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Fluoridation

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Fluoridation Considerations

- Added as Supplement to Natural Occurring Concentrations
- Typically 1 to 1.2 mg/l as Fluoride
- Regulated MCL at 4 mg/l SDA and 2 mg/l DEP
- Halogen and as Oxidant very Active!
- Overdosing causes mottling of teeth and bone deterioration
- When working with fluoridation systems using sodium fluoride, a hardness greater than 75 mg/l will cause severe scaling in the equipment.

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Fluoride Compounds

Compound Name	Formula	Purity	pH
Sodium Fluoride	NaF	97%	7.6
Sodium Fluorosilicate	Na_2SiF_6	98%	3.6
Hydrofluoro-silicic Acid *	H_2SiF_6	23%	1.2

* Because hydrofluosilicic acid is a liquid it is the easiest to feed and requires the least maintenance

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Symptoms of Fluoride Poisoning

When swallowed
- Vomiting
- Stomach cramps
- Diarrhea

When inhaled
- Sharp biting pain in the nose
- Runny nose
- Nosebleed

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