Wastewater Disinfection

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Definition of Disinfection

- Disinfection refers to the reduction of pathogens.
- Disinfection <u>does not</u> mean *sterilization*.

Purpose of Wastewater Disinfection

- Disinfection of WW is practiced to prevent the spread of waterborne illness.
- Disinfection of WW protects potable water supplies from contamination that could overwhelm water treatment processes.
- Disinfection of WW protects recreational water quality and wildlife.

Disinfection Methods

- Chlorine
- Other halogens; I_2, Br_2, ClO_2
- Ozone (O_3)
- Ultraviolet light

Methods other than chlorine will be examined later in this class.

Chlorine Disinfection

- Chlorine disinfects wastewater because it is a strong oxidizer (steals electrons).
- Chlorine will both oxidize pathogens and is toxic to them when absorbed.
- Chlorine is inexpensive, readily available and effective.
- Chlorination of wastewater effluent has been practiced in the U.S. for around 100 years.

Problems With Chlorine Disinfection

- Potential for the creation of chlorinated organics (trihalomethanes).
- Danger involved with handling chlorine or chlorine compounds.
- Residual chlorine causes the destruction of aquatic life in the receiving stream. (Trout are particularly susceptible).

The Clean Water Act

- The Clean Water Act sought to make all waters of the U.S. "fishable and swimmable".
- Residual chlorine compounds can kill fish, so something must be done about the left over chlorine if the intent of the Clean Water Act is to be met.
- NPDES discharge permits typically require non-detectable total residual chlorine (TRC), which means <0.099 mg/L in most cases.

Options for Resolving Residual Chlorine Problems

- Better control of chlorine dosage
- Alternative disinfection methods
- Detoxification of effluent (dechlorination)

Better control of chlorine dosage

- Improves the efficiency of chlorination process
- Reduces disinfection by-product formation
- <u>Does not</u> solve the fish toxicity problem

Dechlorination

- Solves the fish toxicity issue
- Requires careful control to be effective
- Chemicals used for dechlorination can cause other problems

Chlorination Chemicals

Chemical	*Symbol*	*Common Name*
Chlorine Gas	Cl_2	Chlorine
Calcium Hypochlorite	$Ca(OCl)_2$	HTH
Sodium Hypochlorite	NaOCl	Bleach

Safety Concerns: Chlorine Gas

- Severe skin and eye irritant
- Vapors are lethal at 1000 ppm after just a few deep breaths
- Boils at –29.15°F
- 2.5 times heavier than air (sinks to the bottom of a room)
- Will cause organic compounds to *spontaneously* combust and will enhance combustion

Safety Concerns: Hypochlorite Compounds

- Irritant to skin and eyes (may result in sensitization dermatitis)
- Explosive when combined with organic compounds (gasoline, oil, sludge)
- Should never be mixed with <u>anything</u> other than water.

Chlorination Terminology

- ***Dosage:***
  - The amount of chlorine added to the system.

    Generally expressed as a concentration (mg/L) or as an application rate (lbs./day).

Chlorination Terminology

- ***Demand:***
  - Amount of chlorine that is used up by the contaminates in the wastewater.

  Demand is expressed in mg/L.

Chlorination Terminology

- ***<u>Residual:</u>***
  - Chlorine residual is the amount of chlorine remaining after the demand has been satisfied.

    Residual is expressed as mg/L.

    There are three types of residual;

    Free, Combined and Total.

Chlorination Chemistry

- **Hypochlorous acid** (HOCl) is formed when chlorine or chlorine compounds are first added to water to make a solution.
- **HOCl** is the "strong disinfectant" that is very effective at killing pathogens.
- Other chlorine compounds may be formed that are not "strong disinfectants", depending on the chemistry of the water that is being disinfected.

Reaction of Chlorine Gas

$Cl_2 + H_2O \longrightarrow$ **HOCl** & HCl

Chlorine gas and water combine to make hypochlorous acid and hydrochloric acid. This reaction causes a decrease in pH.

Reaction of Calcium Hypochlorite

$Ca(OCl)_2 + H_2O \longrightarrow$ **HOCl** & $Ca(OH)_2$

Calcium hypochlorite and water combine to make hypochlorous acid and calcium hydroxide.

This reaction causes an increase in pH.

Reaction of Sodium Hypochlorite

$NaOCl + H_2O \longrightarrow$ **HOCl** & $Na(OH)_2$

Sodium hypochlorite and water combine to make hypochlorous acid and sodium hydroxide.

This reaction causes an increase in pH.

The *"Strong Disinfectant"*

- It does not matter if we use chlorine gas or the hypochlorites, hypochlorous acid (HOCL) serves as the actual disinfectant.
- Once made up into a solution, the hypochlorous acid can then be used to disinfect effluent.

The Breakpoint Phenomenon (1)

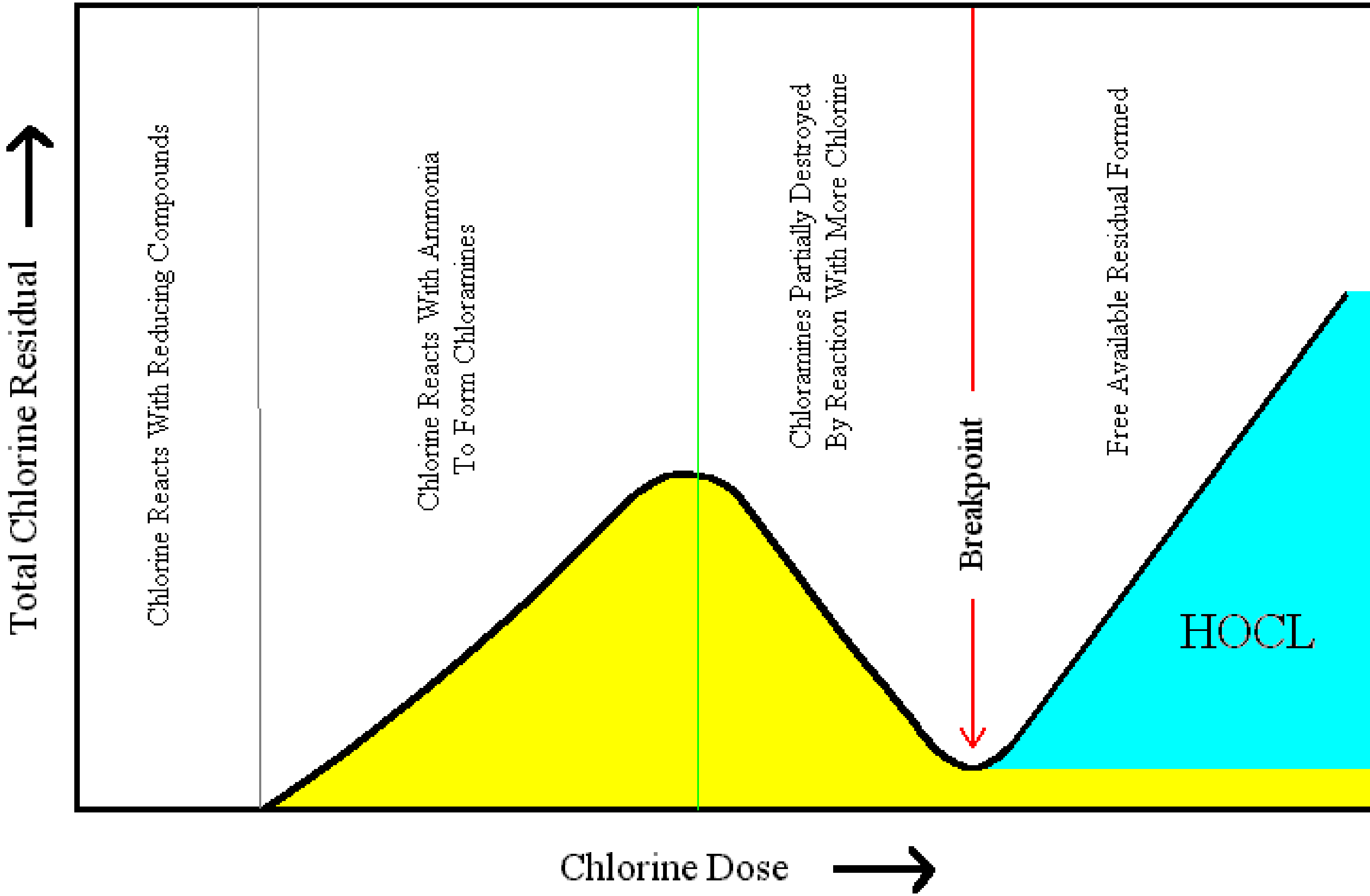
- Because chlorine is a strong oxidizing agent, it first reacts with chemical compounds in the wastewater that will easily give up their electrons (reducing agents like H_2S).
- Next, chlorine reacts with compounds that will share their electrons (such as ammonia) and forms combined compounds (chloramines).

The Breakpoint Phenomenon (2)

- Then, with the addition of more chlorine, the chloramine compounds are broken down.

- Finally, when all of the demand has been satisfied, free chlorine will exist in solution.

The Breakpoint Phenomenon (3)



Wastewater Chlorination

- When disinfecting wastewater, free available chlorine is not needed (or attainable).
- Disinfection of wastewater is performed by chloramines, so the breakpoint is never reached.
- Disinfection using combined chlorine is cost effective and reduces disinfection by-products.

Factors That Effect Chlorination

- Injection point and mixing
- Contact time
- pH
- Temperature
- Chlorine dose
- Turbidity and interferences

The Effect Of Injection Point and Mixing On Chlorination

- Excellent initial mixing is critical to ensure that the chlorine is spread throughout the effluent so that it comes into contact with as many pathogens as possible.

Chlorine Solution Injection Header

Contact Time's Effect On Chlorination

- Adequate contact time is critical to ensuring effective disinfection, because chlorine reactions take time and some pathogens take a while to kill off.
- 30 minutes (at peak flow) is considered the minimum contact time needed for good disinfection.

Chlorine Contact Chamber (Good Design)

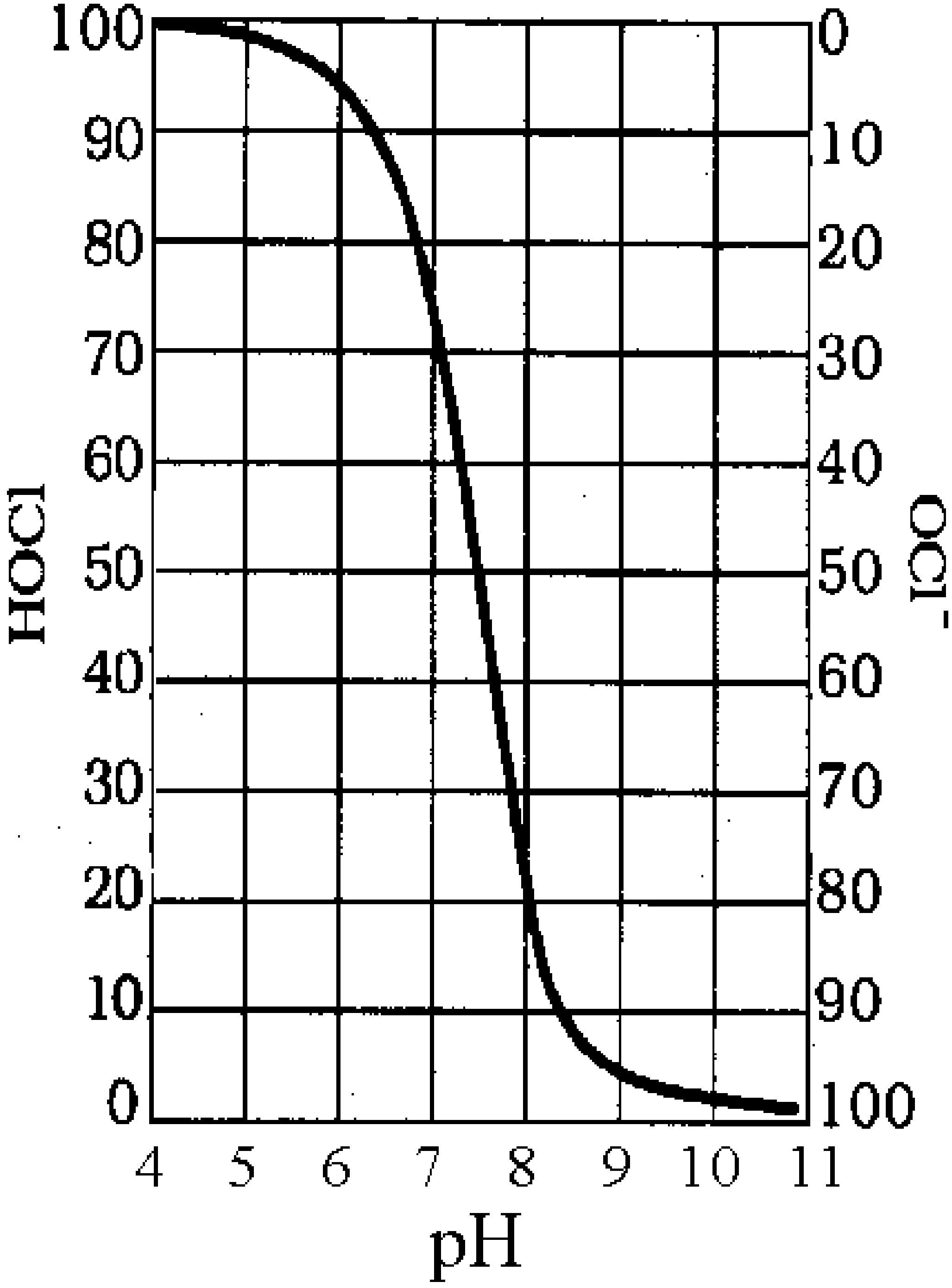
Chlorine Contact Chamber (Not As Good Design)


Chlorine Contact Chamber
(Really Poor Design)

The Effect Of pH On Chlorination

- The pH of the wastewater can change the chlorine dose required for good disinfection.
- The lower the pH, the less chlorine required.
- HOCL disassociates into hydrogen ions and hydroxide molecules based on pH.

pH Effect On HOCL



The Effect Of Temperature On Chlorination

- Colder temperatures slow down the chemical reactions involved with disinfection.
- In extreme cold weather, longer detention times and higher chlorine doses may be needed.

Cold!

The Effect Of Chlorine Dose On Chlorination

- Obviously, the higher the chlorine dose, the more effective the disinfection will be.
- However, increasing detention time is more effective than increasing the chlorine dose, because there is a *minimum contact time* that must occur.

The Effect Of Turbidity and Interferences On Chlorination

- Turbidity and interferences can lower the effectiveness of chlorination in two ways:
  - Turbidity can hide pathogens which prevents them from coming in contact with the chlorine.
  - Interfering substances can exert a high chlorine demand that uses up the chlorine before it can kill the target pathogens.

Dirty Chlorine Contact Chamber

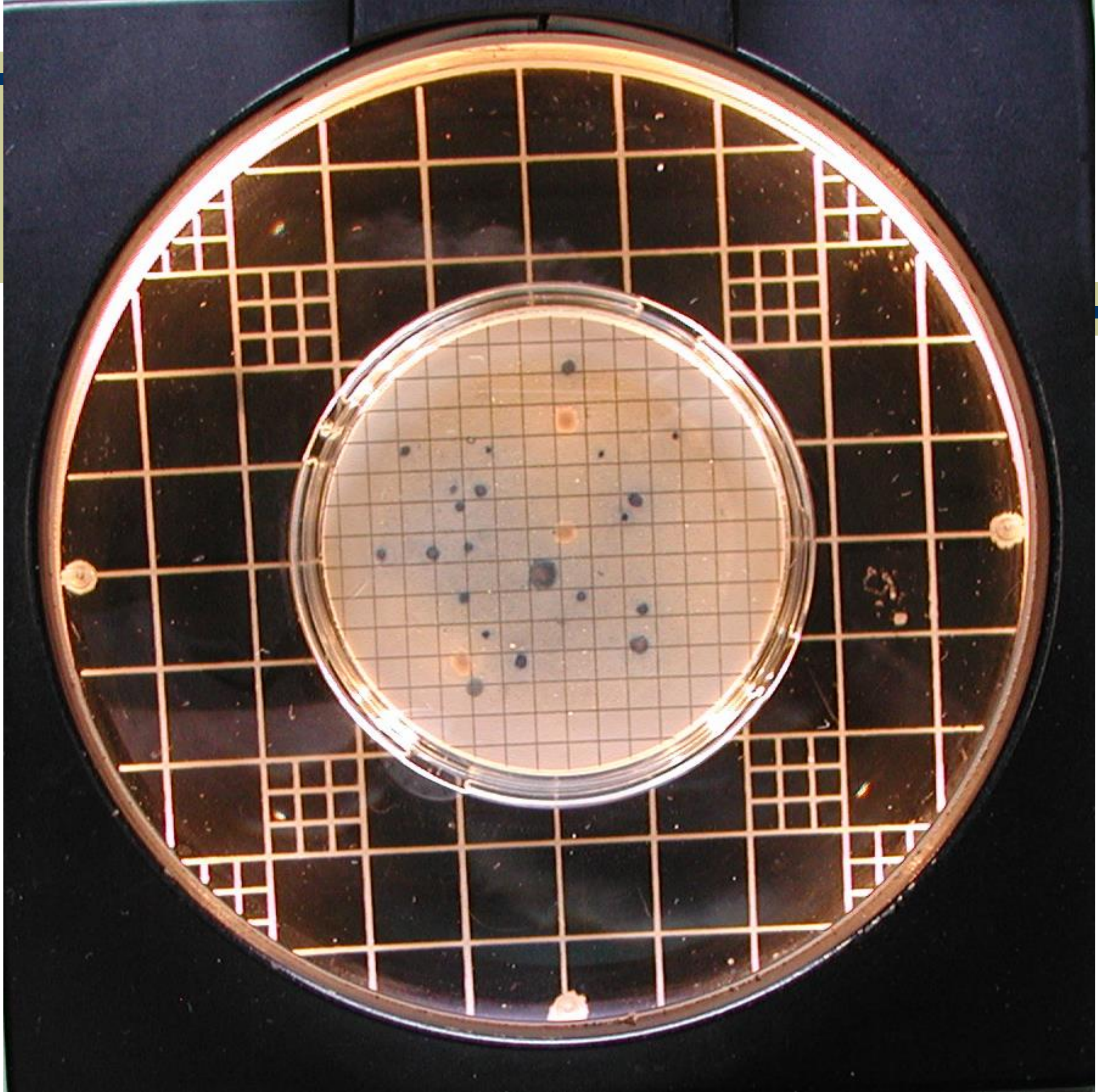
Monitoring The Effectiveness of Disinfectiontion

- How can we tell if our disinfection has been effective at killing off pathogens?

Monitoring The Effectiveness of Disinfection

- The Fecal Coliform group of bacteria are used as *indicator organisms* for monitoring the effectiveness of disinfection.
- Fecal Coliform are not pathogenic.

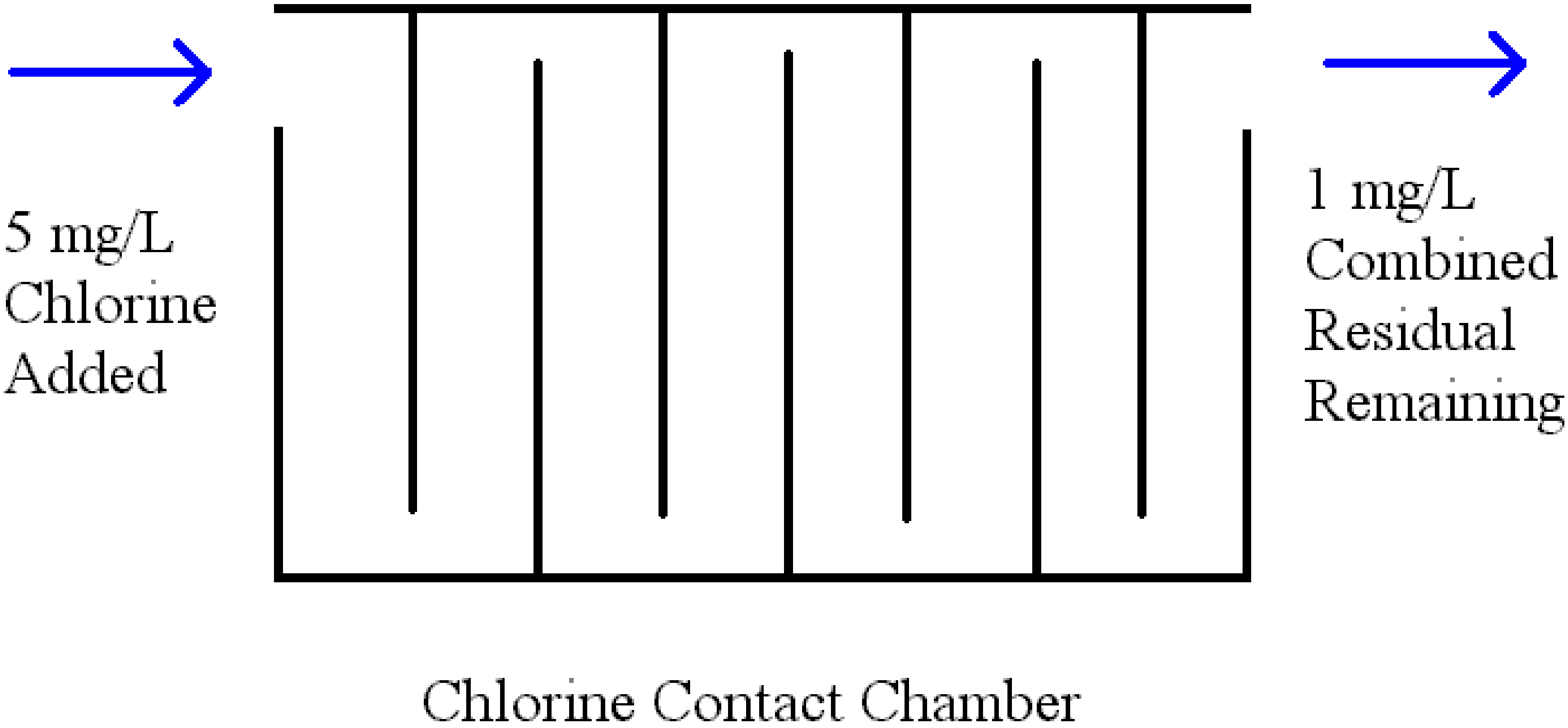
Membrane Filtration of Fecal Coliform



Monitoring The Effectiveness of Chlorination

- Chlorine residual can also be used to demonstrate disinfection, as long as conditions do not change dramatically.

Chlorination Schematic



Target of Dechlorination

- It is the residual chlorine that remains after disinfection has been accomplished that must be dechlorinated.
- Again, this is almost always a combined residual only.

Dechlorination Chemicals

Chemical	*Symbol*	*Form*
Sulfur Dioxide	SO_2	Gas
Sodium MetaBi-sulfite	$NaHSO_3$	Powder
Sodium Sulfite	$NaSO_3$	Liquid

Safety Concerns:
Sulfur Dioxide Gas

- SO_2, while not as dangerous as chlorine, is a severe irritant.
- SO_2 is immediately dangerous at a concentration of 400-500 ppm.
- The maximum allowable concentration over an 8-hr exposure is 10 ppm.

Safety Concerns:
Sodium Sulfite and Bi-sulfite

- Sodium bi-sulfite powder and tablets can cause eye and skin irritation (wear goggles and rubber gloves when handling).
- Do not mix either of these chemicals with anything other than water and store them away from other substances.

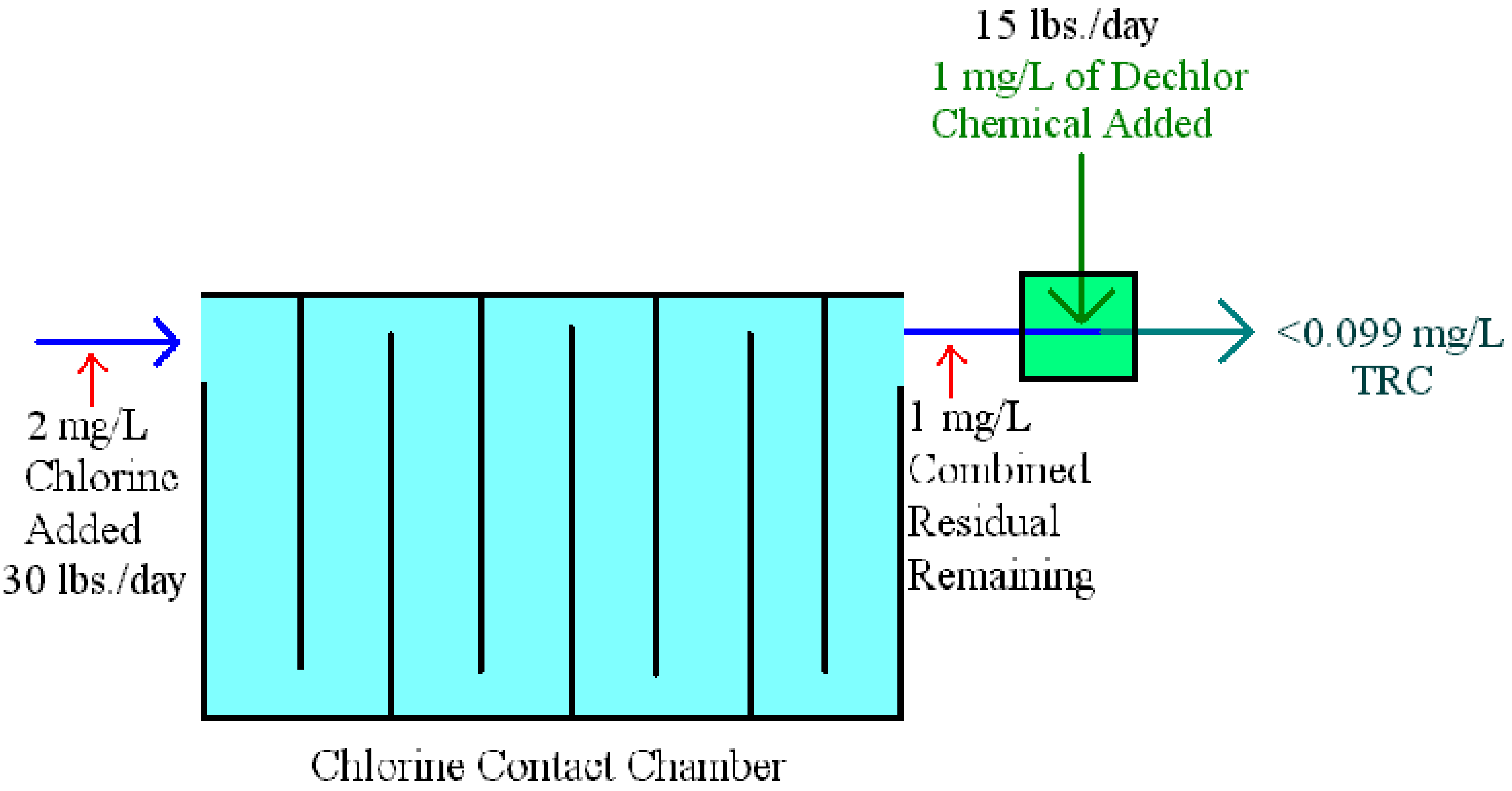
Chemistry of Dechlorination

- All of the sulfur based dechlorination agents work by converting positive chlorine ions into negative chloride ions by providing electrons.
- Small amounts of sulfuric and hydrochloric acid are formed as by-products.

Dechlorination Application

- It takes 0.9 mg/L of SO2 to remove 1.0 mg/L of total residual chlorine (TRC).
- However, because much of the chlorine added to wastewater is used up during disinfection, the amount of dechlorination chemical required should only be around 1/2 the chlorine applied.
- Unlike disinfection chemistry, dechlorination happens almost instantly, so no contact time is needed.

Dechlorination Schematic



Factors That Effect Dechlorination

- Adequate mixing is by far the most important aspect needed for efficient and complete dechlorination.
- If the proportions of chlorine to dechlorinating agent are out of line, poor mixing is most likely to blame.
- Flow proportioning greatly improves efficiency.

Good Injection and Mixing Of Dechlorination Chemicals

Chlorination/ Dechlorination Equipment

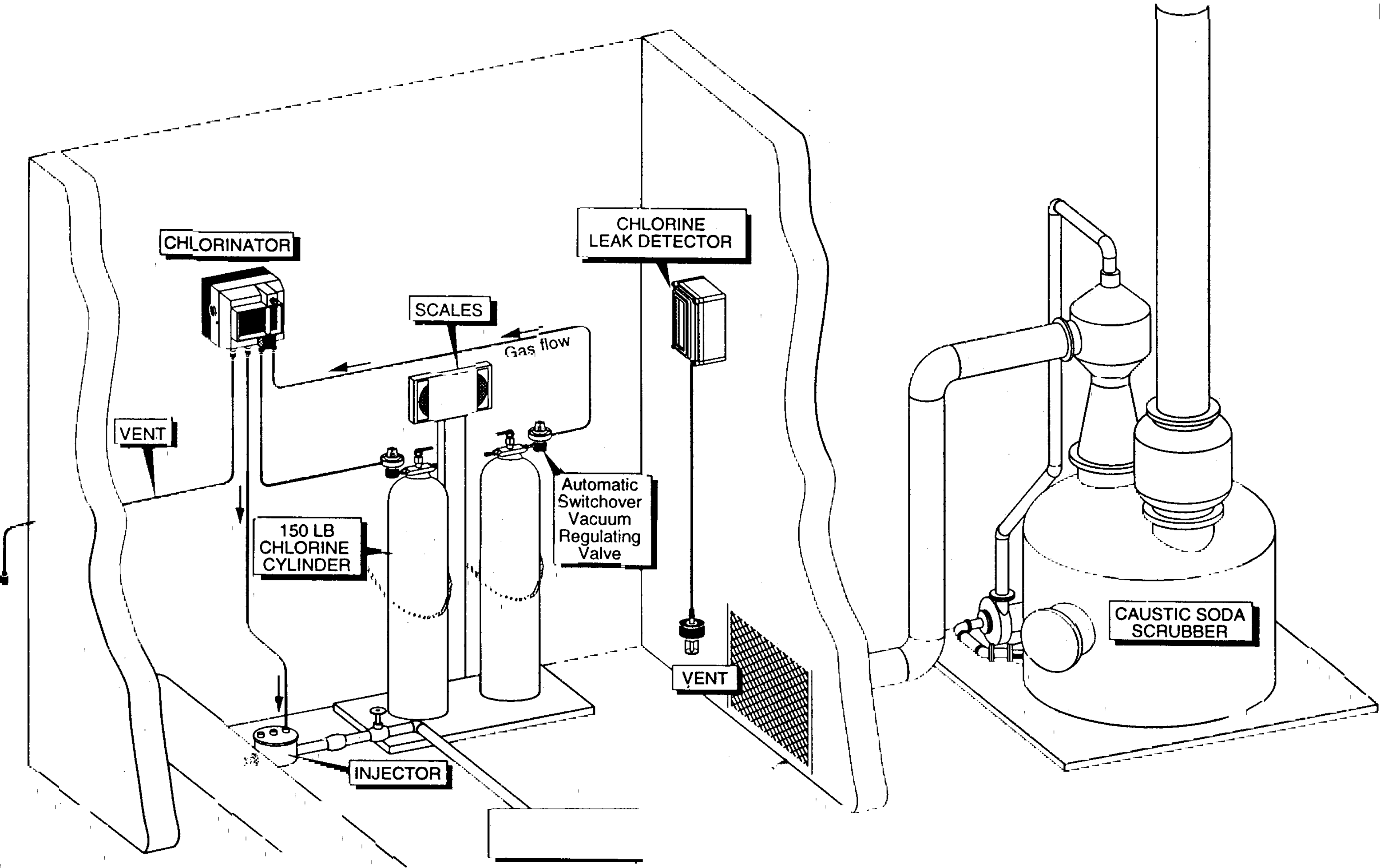
- Tablet feeders
- Liquid feeders
- Gas delivery systems

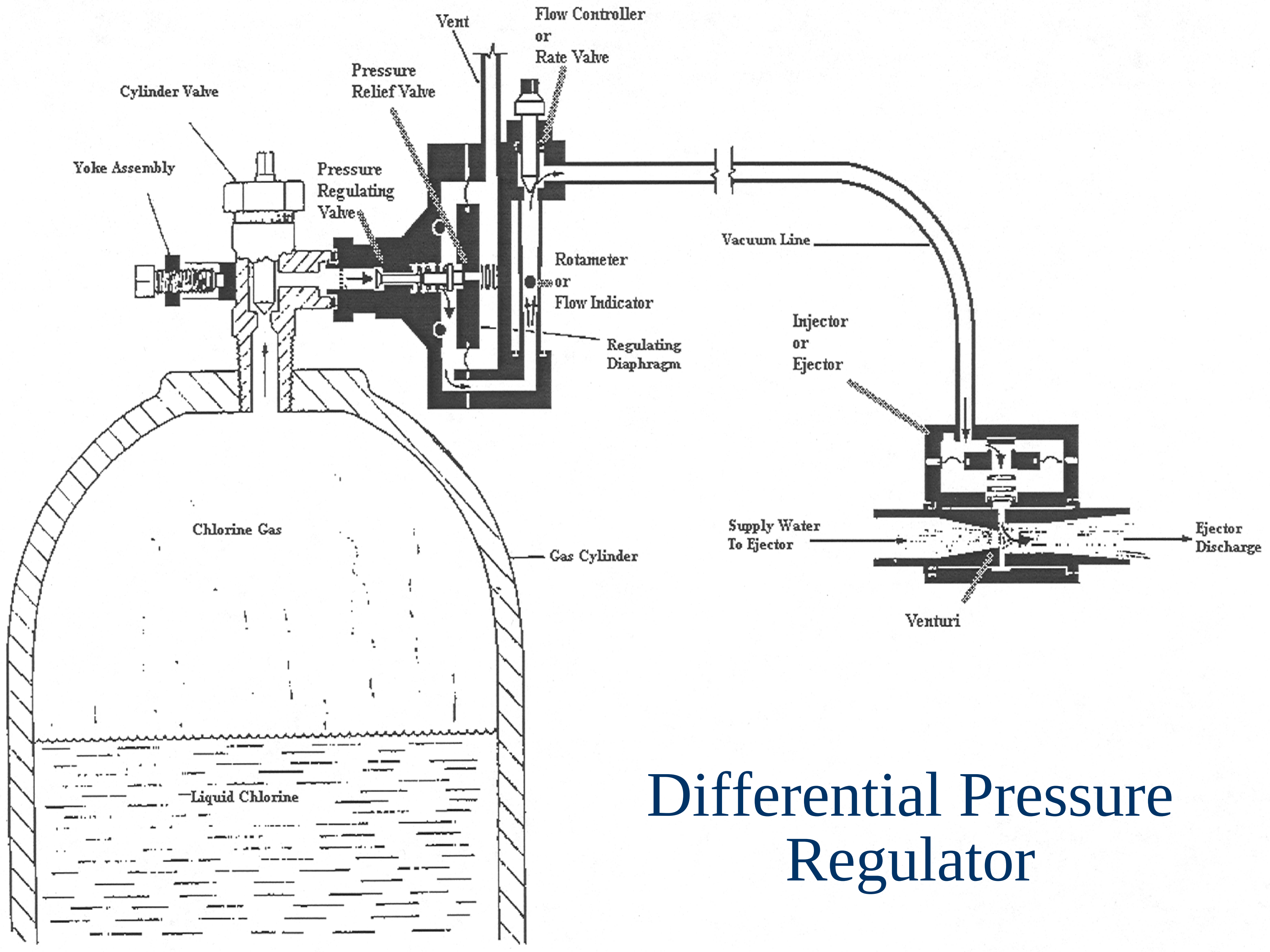
Tablet Chlorine Feeder

Tablet Dechlorination Feeder

Liquid Chlorine Feed System

Schematic of a Vacuum Gas Feed System



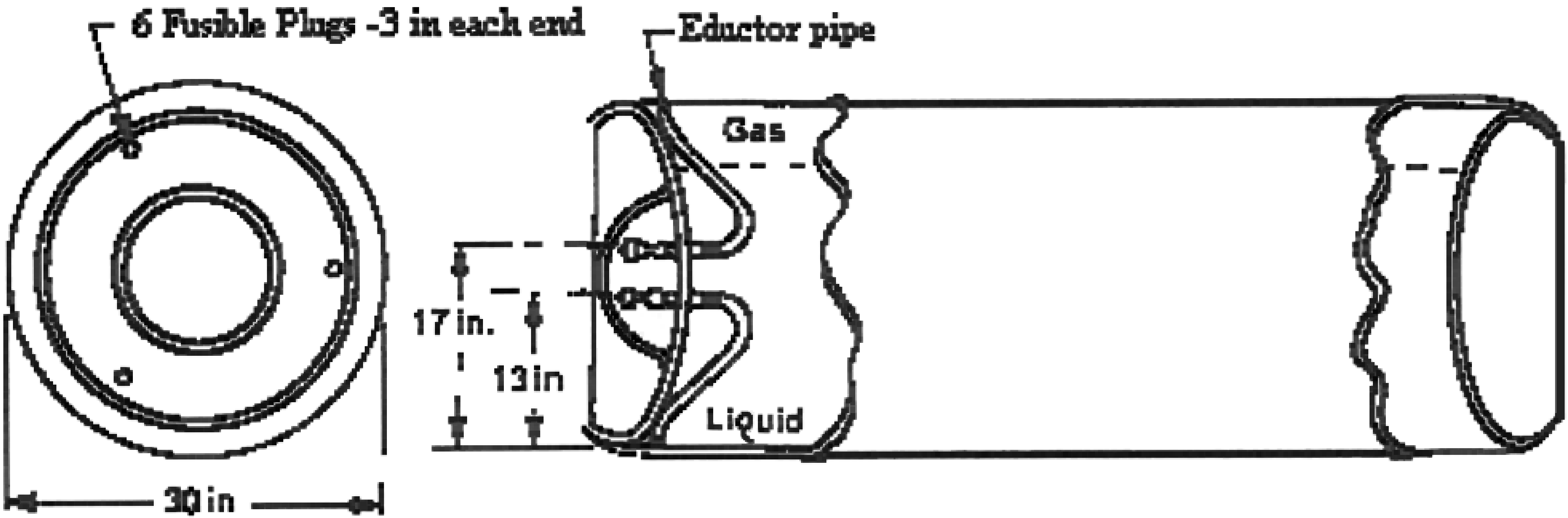


Differential Pressure Regulator

150 lb. Chlorine Containers

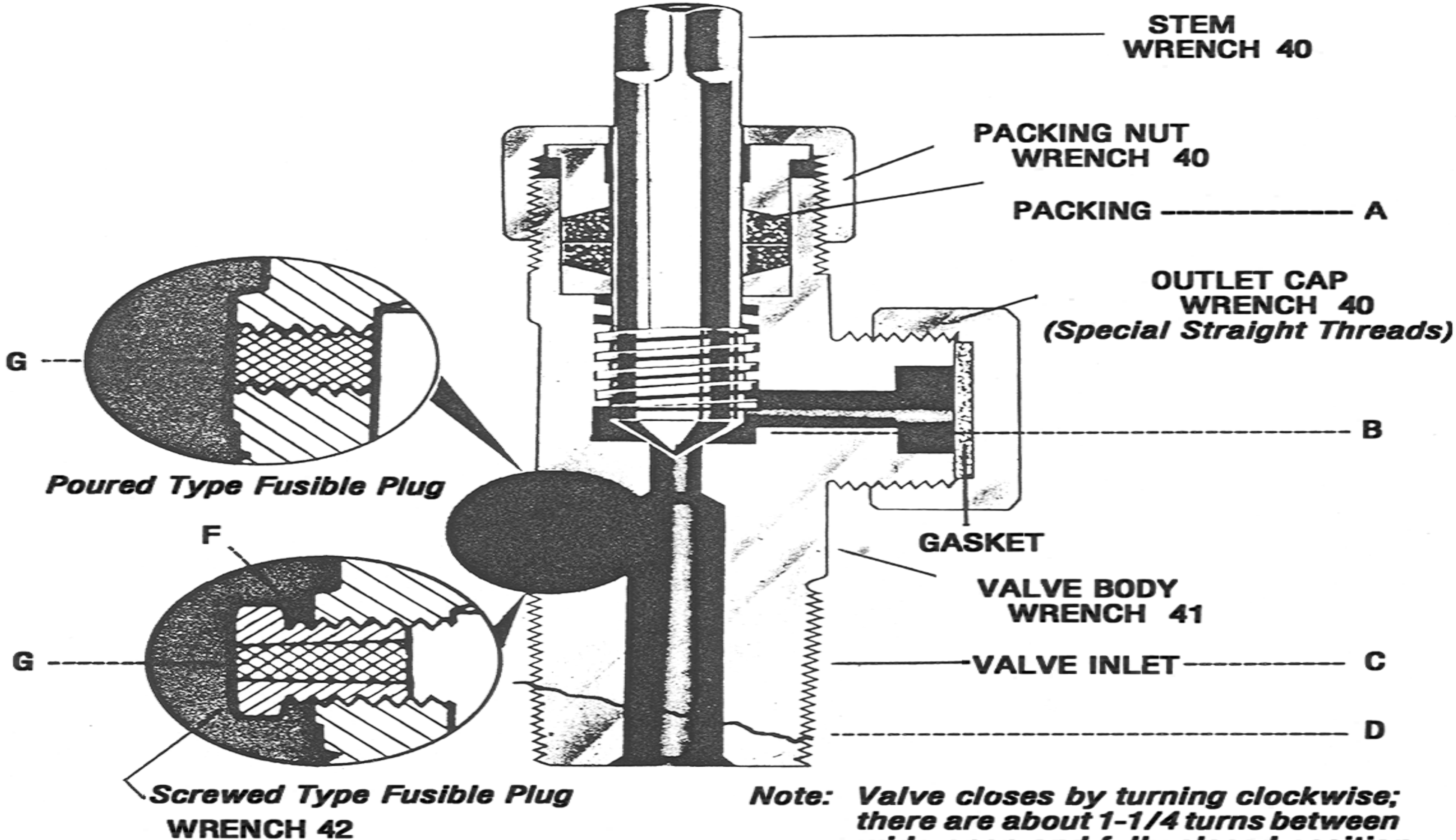
One Ton Chlorine Containers

One Ton Cylinder Cross Section



Chlorine Cylinder Valves

- Valves are specially designed for this purpose.
- <u>One full turn</u> of the valve permits maximum discharge.
- Valves are equipped with fusible plugs that melt at 158° – 165° F to prevent fire rupture.
- A new lead gasket should be used each time a connection is made to the valve.



Note: *Valve closes by turning clockwise; there are about 1-1/4 turns between wide-open and fully closed position. All threads are right-hand threads.*

TYPICAL VALVE LEAKS OCCUR THROUGH . . .

A - VALVE PACKING GLAND

B - VALVE SEAT

C - VALVE INLET THREADS

D - BROKEN OFF VALVE

E - VALVE BLOWN OUT

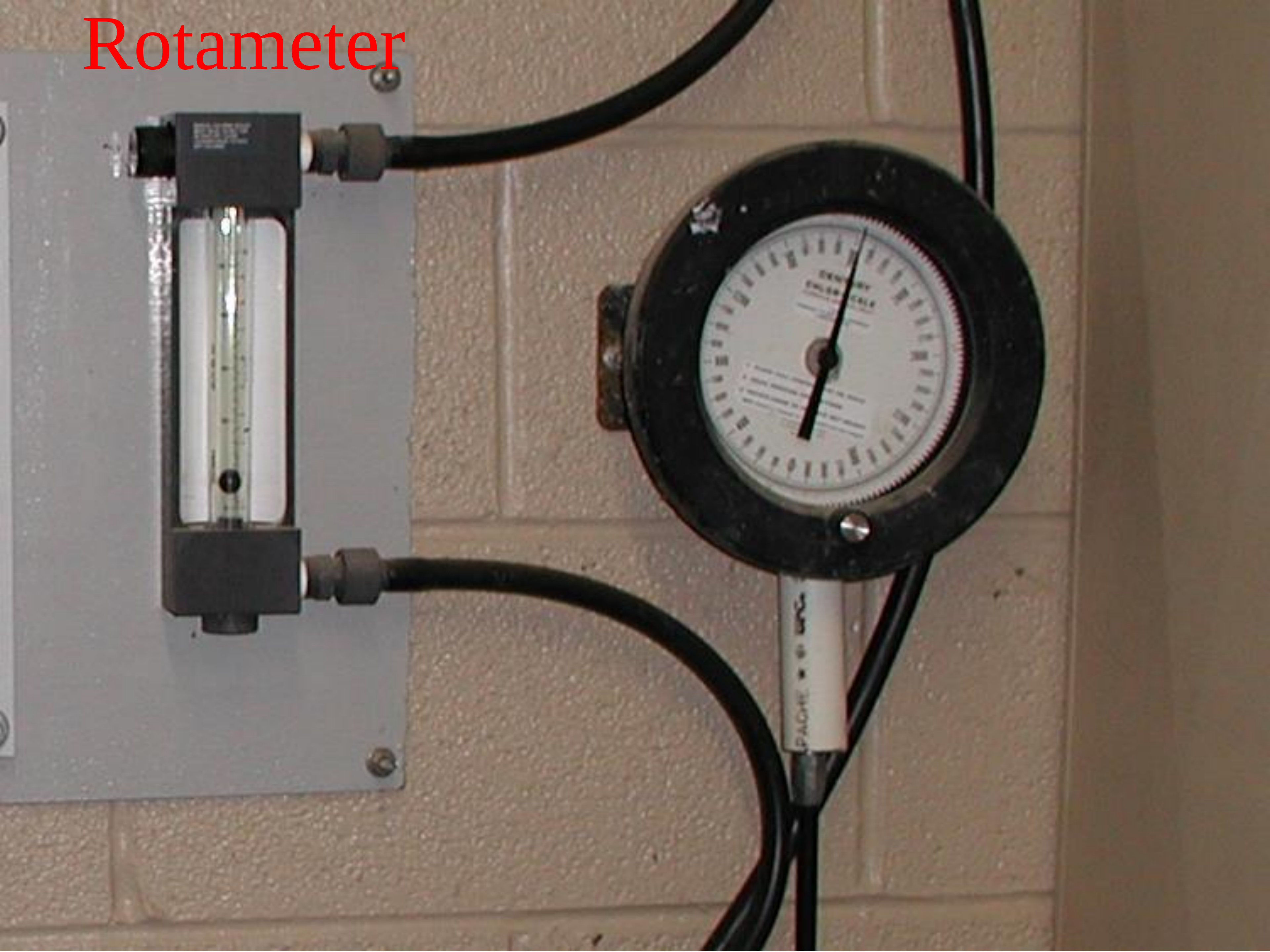
F - FUSIBLE PLUG THREADS

G - FUSIBLE METAL OF PLUG

H - VALVE STEM BLOWN OUT


Ejector (or injector)

Rotameter



Vacuum Regulator On 150 lb. Cylinder

Sulfur Dioxide Feed System

Gas Chlorination/ Dechlorination Equipment Problems

- Freeze – up
- Plugged ejector
- Vacuum leaks

Freeze – Up (1)

- Even though chlorine and sulfur dioxide gas boil at a low temperature, only a limited amount can be withdrawn from a container.
- If you attempt to feed more gas than can be withdrawn, the cylinder will ice over and the gas flow will stop.

Freeze – Up (2)

- At room temperature, a 150 lb. cylinder can deliver about 40 lbs./day of gas.
- At room temperature, a 1-ton cylinder can deliver about 400 lbs./day of gas.

Plugged Ejector

- If the ejector of a vacuum gas delivery system becomes plugged, little or no vacuum will be created.
- Check the vacuum gauge on the system to identify this problem, or shut off the cylinder valve, remove the vacuum line from the ejector and feel if a vacuum is being created.

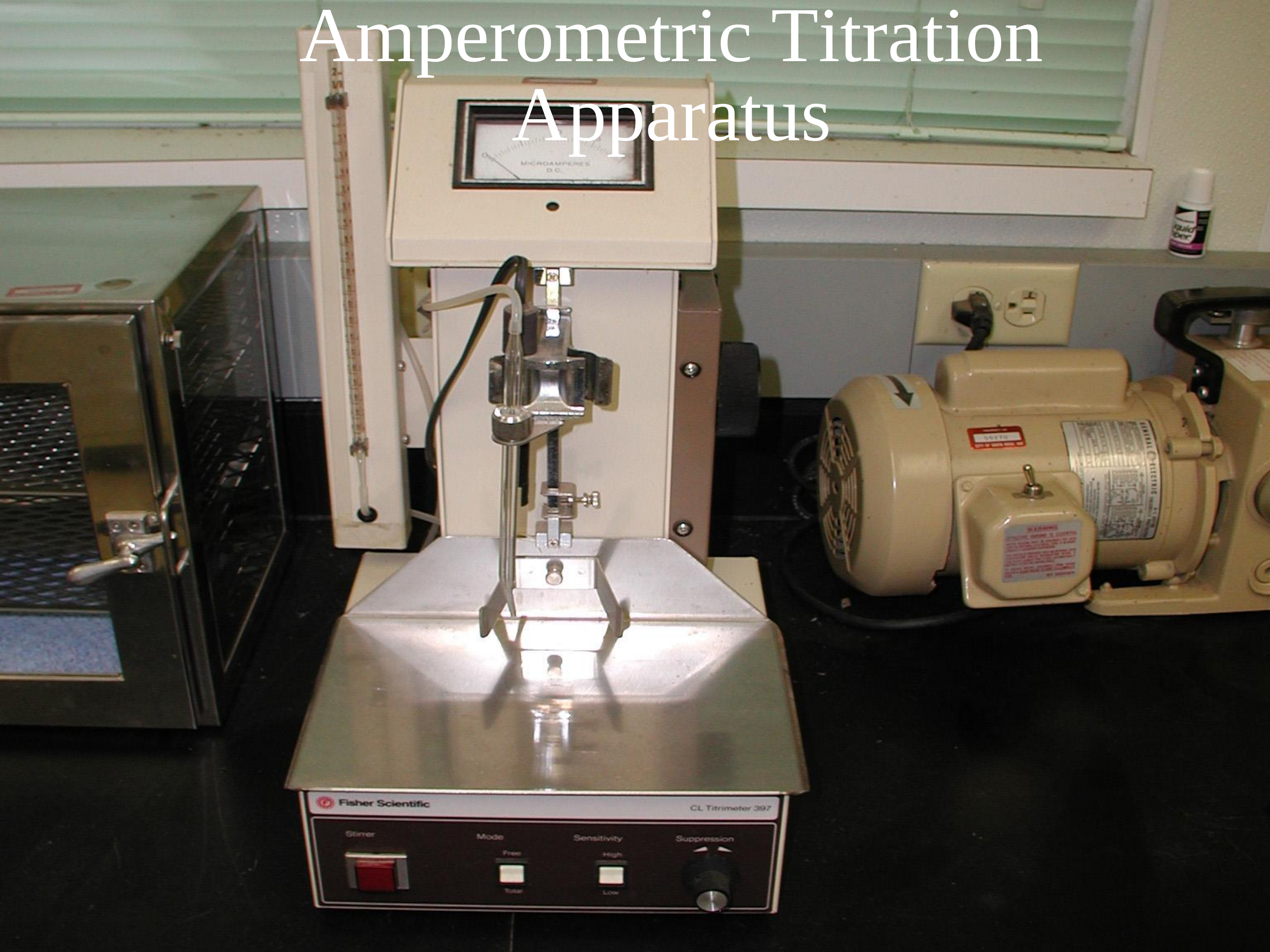
Vacuum Leaks

- Vacuum leaks will make the system appear to be functioning, but not enough gas will be delivered.
- Check for vacuum leaks by shutting off the cylinder valve and observing the rotameter float. If the float does not drop to zero, the system has a vacuum leak.

Measuring Chlorine Residuals In Wastewater For NPDES

- Three methods can be used to measure TRC in wastewater for NPDES permit monitoring. Theses are:
  - Amperometric Titration
  - Iodometric Probe
  - DPD

Amperometric Titration Apparatus



Iodometric Probe

- This method relies upon the measurement of iodine that is released proportionally to the amount of chlorine in a sample.
- Standards must be carefully made each time this test is run.
- The probe and reagents have a limited shelf life.

DPD Method

- The DPD method uses a color change to indicate the amount of TRC.
- A spectrophotometer or a dedicated filter photometer are required for NPDES monitoring and reporting.
- The methodology is described in:

  <u>Standard Methods for the Examination of Water and Wastewater.</u>

Spectrophotometer

Filter Photometer

Alternative Disinfection Methods

- Other halogens; I_2, Br_2, ClO_2
- Ozone (O_3)
- Ultraviolet light

Other Halogens

- I_2, Br_2 and ClO_2 can be used as disinfectants, but they suffer the same problems as chlorine (toxic residuals, handling and safety issues).
- Other ways of making chlorine are also available, such as hypochlorite generators and MIOX™ systems.

Hypochlorite Generator

MIOX™ System

Ozone Disinfection

- Ozone (O_3), is a strong oxidizer, much like chlorine.
- Ozone breaks down into O_2, so the left over residual is not toxic.
- Ozone must be generated on site, which makes it expensive and highly maintenance intensive.

Ultraviolet Light Disinfection (1)

- UV light disinfects by rendering pathogens unable to reproduce as well as directly killing them.
- High intensity, specific wavelengths are used.
- No chemicals are added, so there is no toxic residual.

Ultraviolet Light Disinfection (2)

- UV disinfection only works on effluents that have a low TSS (< 20 mg/L).
- UV systems can be comparatively small when compared to chlorination systems, because of the low detention time needed (2 – 5 minutes).

Large Open Channel UV System

Small Open Channel UV System

Large Closed Channel UV System


UV Lamps

The End