



Disinfection, Chlorination and Oxidation

Daniel B. Stephens & Associates, Inc.

Chlorination/Disinfection Glossary

- Bacteria: living single-celled microscopic organisms having characteristics of both plants and animals; often useful but may also cause disease

- Chloramines: chemical compounds formed from the reaction of chlorine with ammonia (NH_3); also called combined chlorine (NOTE toxicity for dialysis patients)

- Chlorination: application of chlorine to water, generally for the purpose of disinfection, but also for other purposes such as odor control

Chlorination/Disinfection Glossary

- Coliform bacteria: bacteria used as an indicator of pollution; divided into two groups - total coliform (TC) and fecal coliform (E. coli. - found in the intestinal track of warm-blooded animals); fecal coliform is an indication of pollution.

- Chlorine demand: the difference between the amount of Cl_2 added to water (Cl_2 dose) and the amount of Cl_2 remaining after a period of contact time (Cl_2 residual)

  Cl_2 demand (mg/L) = Cl_2 dose (mg/L) – Cl_2 residual (mg/L)

Chlorination/Disinfection Glossary

- Disinfection: the addition of chlorine, ozone, UV light, etc. to water in order to kill or inactivate disease causing organisms; effectiveness measured using the coliform test

- Free available Cl_2: portion of total Cl_2 residual not combined with ammonia; free Cl_2 includes hypochlorous acid (HOCL) and hypochlorite ion (OCl^-)

Chlorination/Disinfection Glossary

- Pathogens: disease causing organisms such as bacteria, viruses, protozoa; examples are typhoid, cholera, dysentery, poliomyelitis, giardiosis and cryptosporidiosis

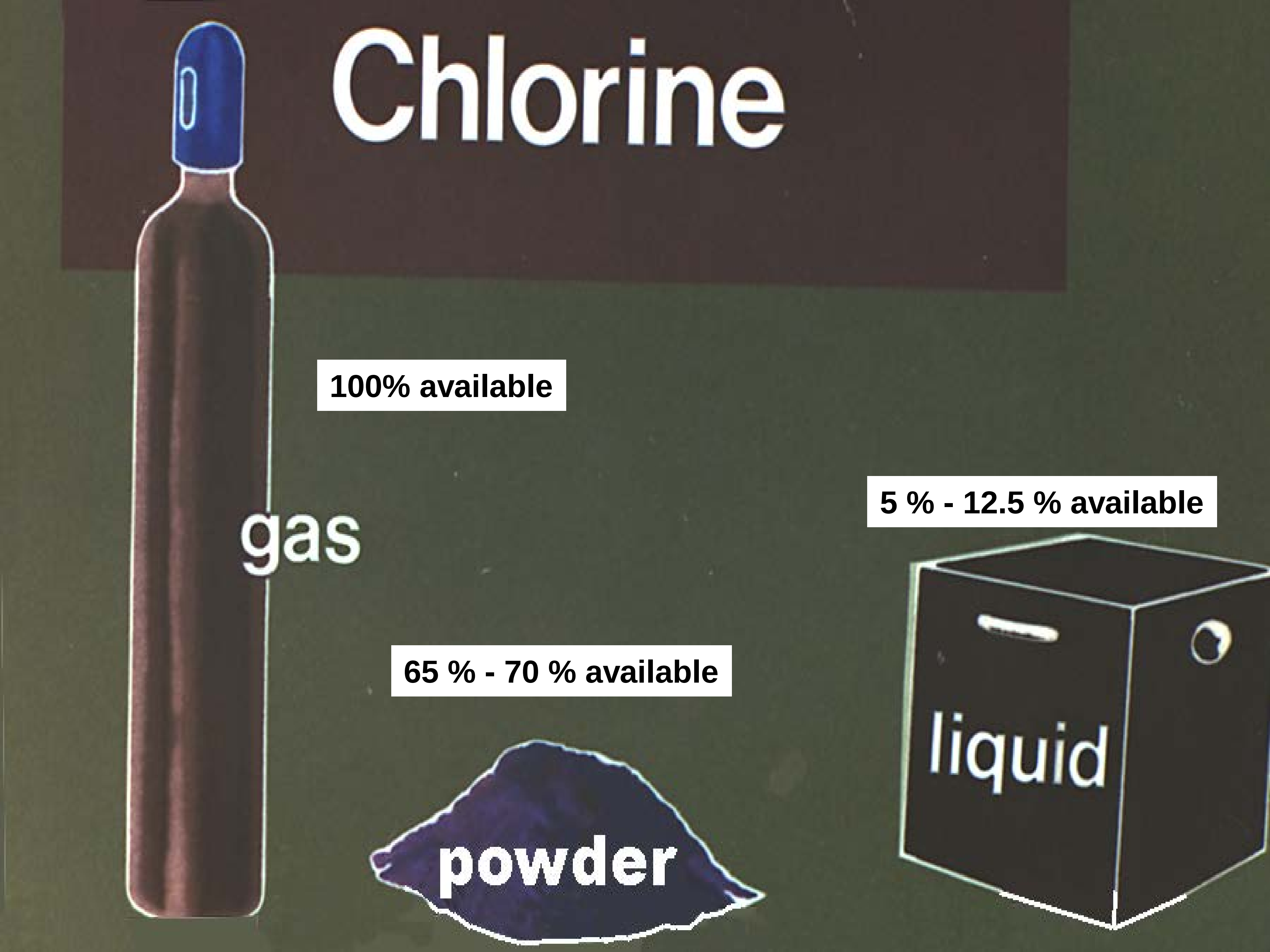
- Sterilization: process that makes water free from all living organisms

Introduction to Chlorine (Cl_2)

Cl_2, due to it relatively low cost, availability, ease of use and **one other important reason**, is the most commonly used disinfectant/oxidant for this purpose.

Chlorine is available in 3 forms:

- Chlorine gas
- sodium hypochlorite solution
- Calcium or sodium Hypochlorite powder (HTH)


Chlorine
100% available
gas
5 % - 12.5 % available
65 % - 70 % available
liquid
powder

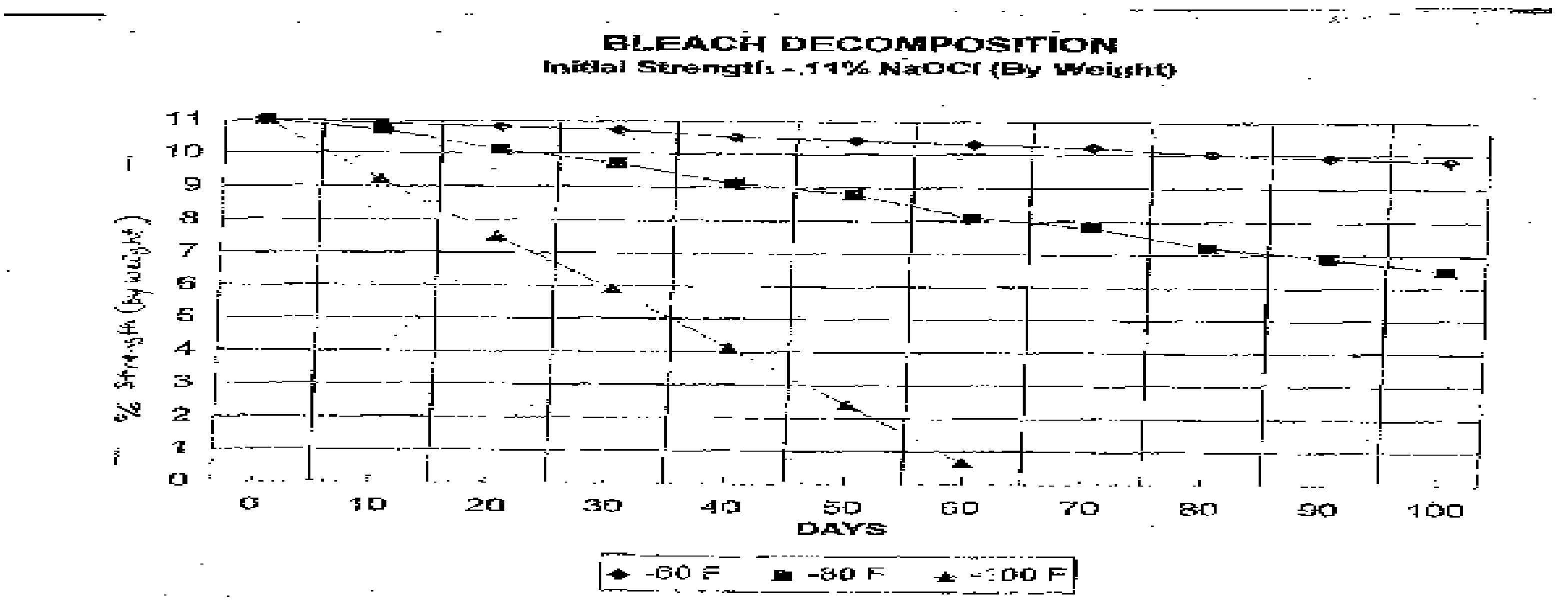
Chlorine Strength, Storage and Aging

Sodium Hypochlorite Concentrations vs Specific Gravity

(USA BlueBook Operator's Companion, 10th ed. page 116)

Trade %	Sp Gr	Trade %	Sp Gr
1.0	1.020	9.0	1.129
2.0	1.034	10.0	1.142
3.0	1.048	11.0	1.155
4.0	1.062	12.0	1.168
5.0	1.076	13.0	1.181
6.0	1.089	14.0	1.193
7.0	1.103	15.0	1.206
8.0	1.116		

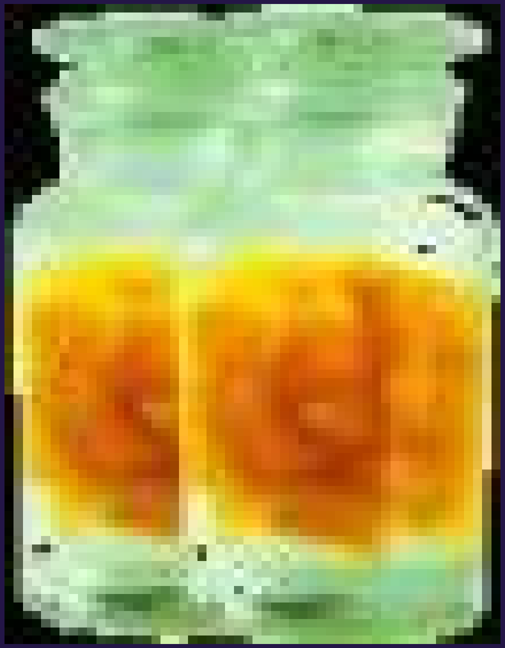
Chlorine Strength, Storage, and Aging

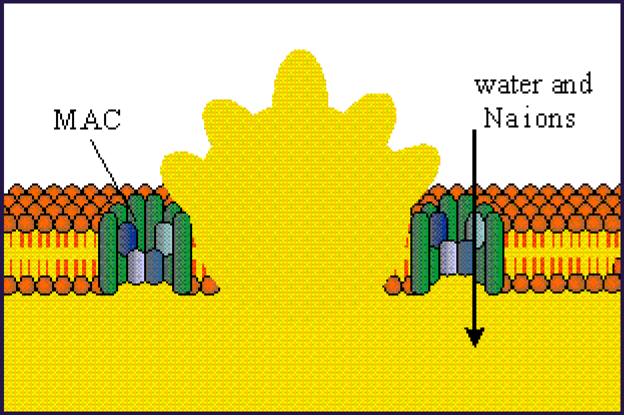


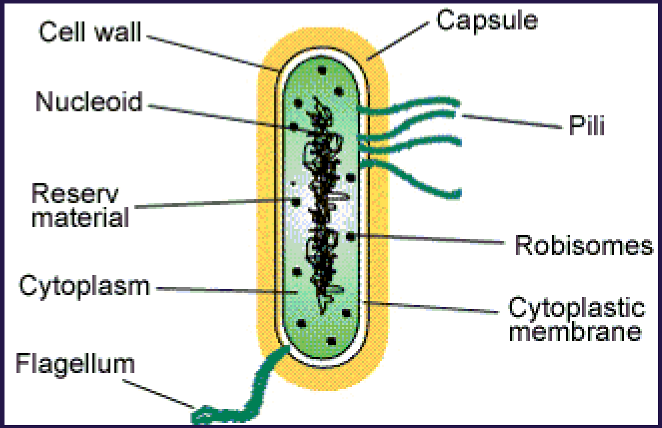
Properties of Cl_2

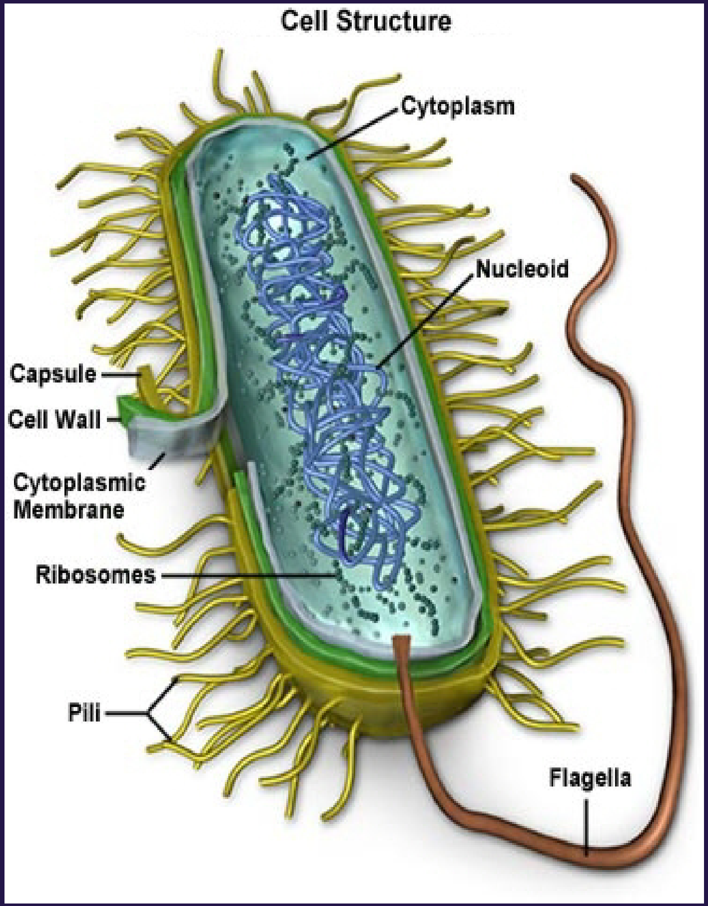
Cl_2 gas

- Amber-yellow in color
- Containing 99.5% pure Cl_2
- Has a penetrating and distinctive odor
- Slightly heavier than water
- 2½ heavier than air
- Has very high coefficient of expansion; i.e., a temperature change from 50°F to 85°F will cause a volume increase from 84% to 89%
- No Cl_2 cylinder should be filled over 85% capacity (see above characteristic)
- One liter of liquid Cl_2 can evaporate to produce 450 liters Cl_2 gas
- Cl_2 is non-flammable & non-explosive but it will support combustion




MAC
water and
Naions


Cell wall
Capsule
Nucleoid
Pili
Reserv
material
Robisomes
Cytoplasm
Cytoplastic
membrane
Flagellum


Cell Structure
Cytoplasm
Nucleoid
Capsule
Cell Wall
Cytoplasmic
Membrane
Ribosomes
Pili
Flagella

The Reaction of Chlorine with Water

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

•Hypochlorous acid, HOCl is one of two free available chlorine residual forms. Due to the ease with which it penetrates into and kills bacteria, it is the most effective form of free residual for disinfection.

•However some of the HOCl dissociates to form an acid.

The Reaction of Chlorine with Water

$$HOCl \rightarrow H^+ + OCl^-$$

- Hypochlorite ion is the second type of free available Cl_2 residual and is a relatively poor disinfectant, primarily because of its inability to penetrate into the bacteria.

- In addition to the hypochlorite ion, hypochlorous acid also releases a hydrogen ion, an acid that can lower the pH if insufficient alkalinity is present.

Effectiveness

- The effectiveness of Cl_2 is based on 5 important factors
  - pH
  - Temperature
  - Concentration
  - Contact time
  - Demand

Effectiveness

- pH strongly influences the ratio of HOCl to OCl^-
  - Low pH values favor the formation of HOCl, the more effective free residual.
  - High pH values favor the formation of OCl^-, the less effective free residual.
  - As pH increases from 7 to 10, the OCl^- begins to predominate and the time required for free residual to effectively disinfect increases.

Effectiveness

- Temperature
  - The higher the temperature, the more effective chlorination.
  - Lower temperatures slightly favor the formation of HOCl
  - Lower temperatures allow Cl_2 residuals to persist somewhat longer.
  - Chemical and biological reaction rates increase as the temperature increases, making Cl_2 more effective at higher temperatures.

Effectiveness

- Concentration of Cl_2
  - Time dependent for different organisms.
  - Providing conditions remain constant, as the contact time is increased, less concentration is needed to accomplish the same level of disinfection.
  - As dosage concentration is increased, contact time can be decreased.

Effectiveness

- Contact Time
  - The destruction or inactivation of an organism is directly related to the contact time.

Effectiveness

- Demand: The inorganic and organic material in raw and finished water take part in the reactions with Cl_2
  - Reaction with ammonia (NH_3) is one of the most common.
  - NH_3 can result from decaying vegetation or from domestic and industrial waste.
  - Cl_2 reacts with NH_3 to form chloramines, or combined chlorine residual.
  - Uses the chlorine that would otherwise be available for disinfection.
  - Other demand-causing reactions include Fe, Mn, S compounds (stoichiometry), turbidity, TOC/DOC, biofilm.

Formation of Chloramines

$NH3 + \text{chlorine} \rightarrow NH_2Cl + H_2O$

ammonia monochloramine (pH > 7.5)

$NH_2Cl + \text{chlorine} \rightarrow NHCl_2 + H_2O$

dichloramine (pH < 7.5)

$NHCl_2 + \text{chlorine} \rightarrow NCl_3 + H_2O$

trichloramine (pH < 7.4)

Formation of Chloramines

- The formation of chloramine compounds depends on the pH of the water and the presence of ammonia.
  - **C**hloramines are a combined available chlorine which is a less active oxidizing agent than free available chlorine, but it has a longer lasting residual.
  - 25 times the amount of combined available chlorine is needed to be as effective as free available chlorine.
  - Toxicity for dialysis patients (GAC)

Breakpoint Chlorination

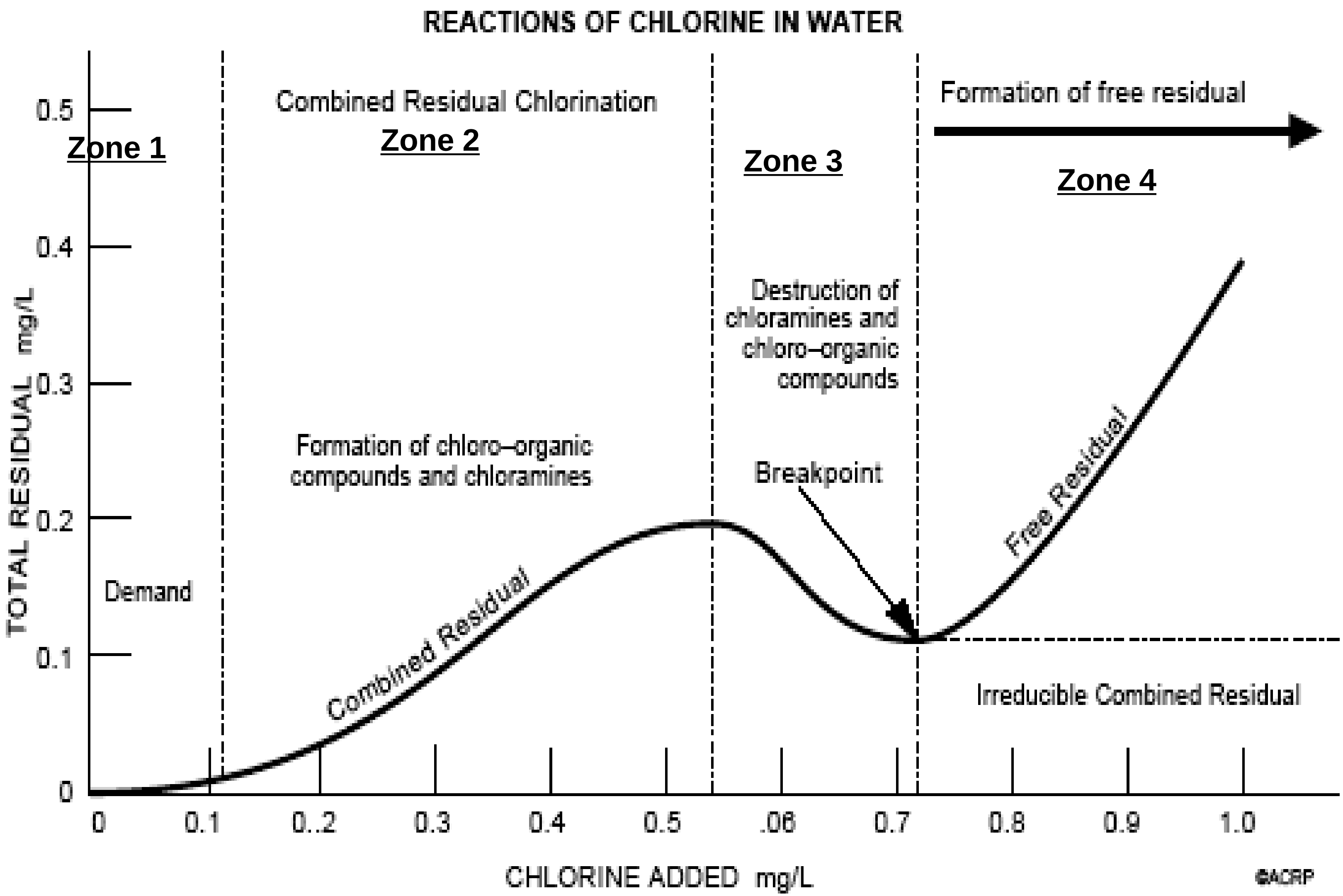
Chlorine Demand

The consumption of chlorine used for disinfection

What is added		What is used		What remains
Dosage	–	**Demand**	=	**Residual**

Demand:

Organics
Microorganisms
Ammonia-Nitrogen
Nitrate
Iron
Silt



Breakpoint Chlorination Curve

Taste and Odor Thresholds

Compound	Taste/Odor Threshold
Free HOCl	20 mg/L
Monochloramine	5 mg/L
Dichloramine	0.8 mg/L
Nitrogen trichloride	0.02 mg/L

Operational Considerations

- There may be times when chlorine taste and odor complaints become a problem in the distribution system.
- This problem is generally related to high combined residuals and inadequate free residual.
- The solution to this problem may be to increase the chlorine dose rate to get past the breakpoint.

Operational Considerations

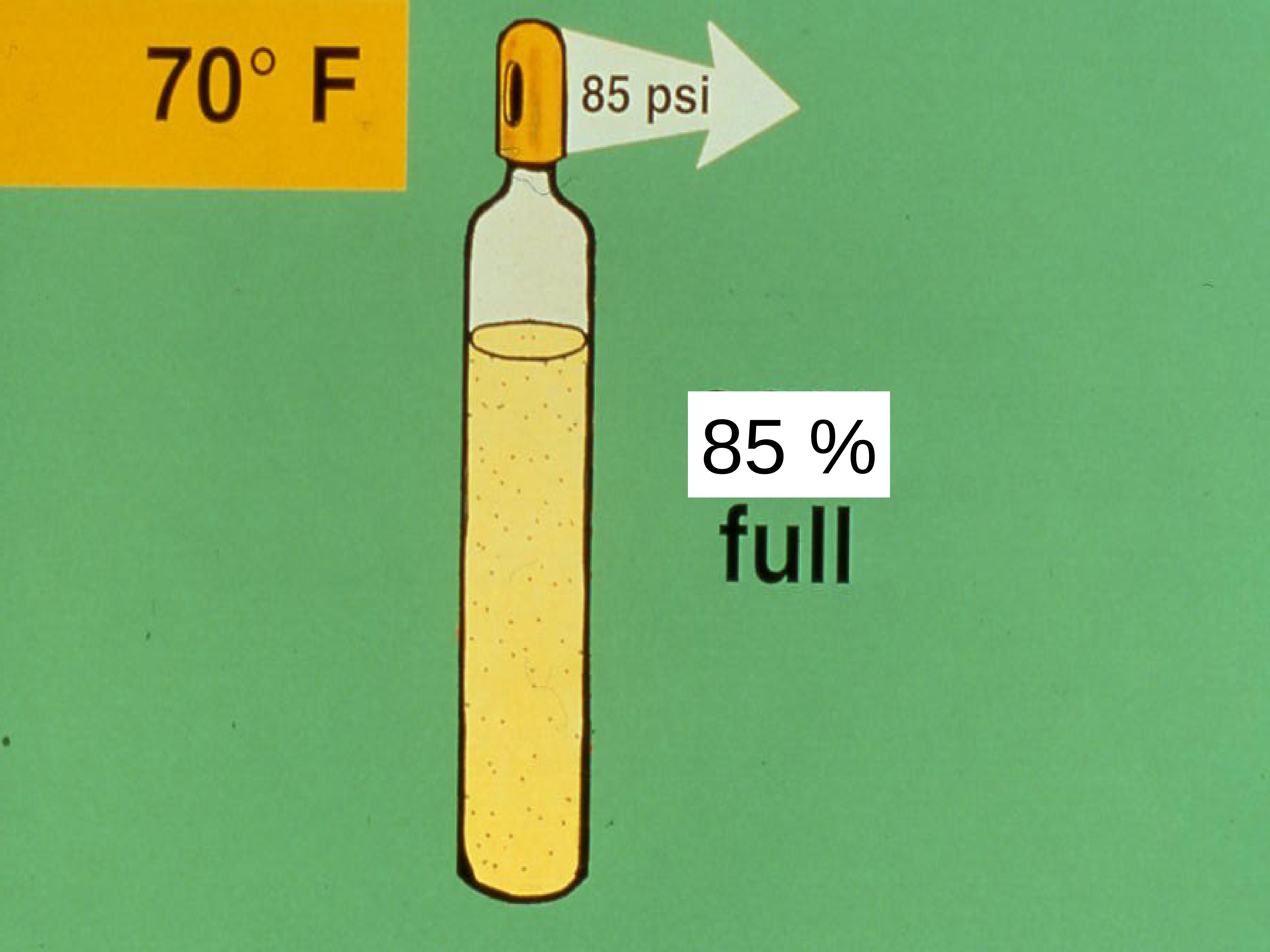
- As a rule of thumb, the free residual should be at least 85% of the total residual in order to prevent chlorine taste and odor problems and insure an adequate free residual for effective disinfection.
- A sudden increase in combined chlorine may signify the presence of organic contaminants such as dirt and debris.
- The sudden presence of organic material may result from a line break, loss of pressure or unprotected cross connection such as lawn irrigation, etc.

Chlorine Residual Testing
DPD Colorimetric

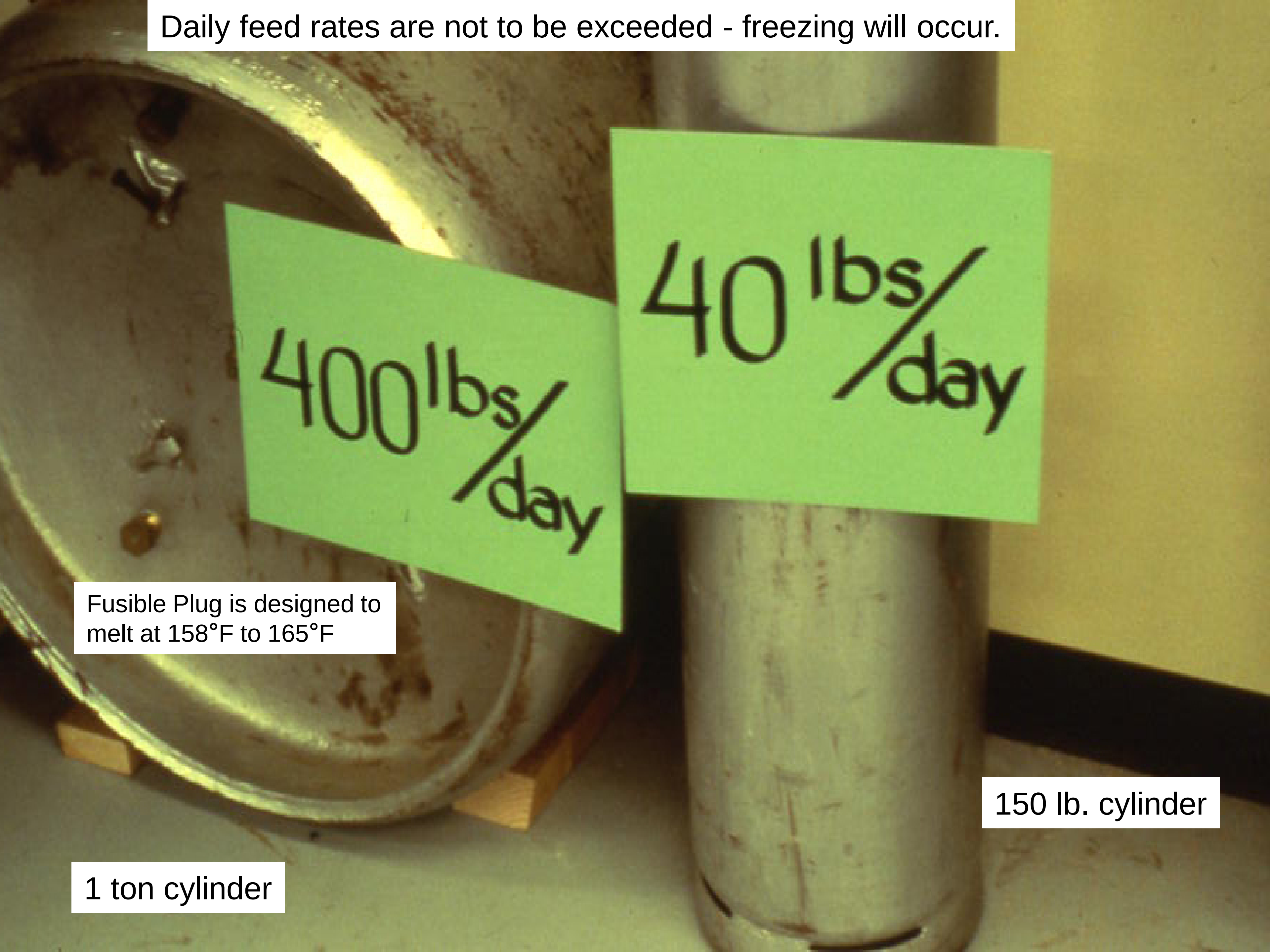
Chlorine Residual Testing

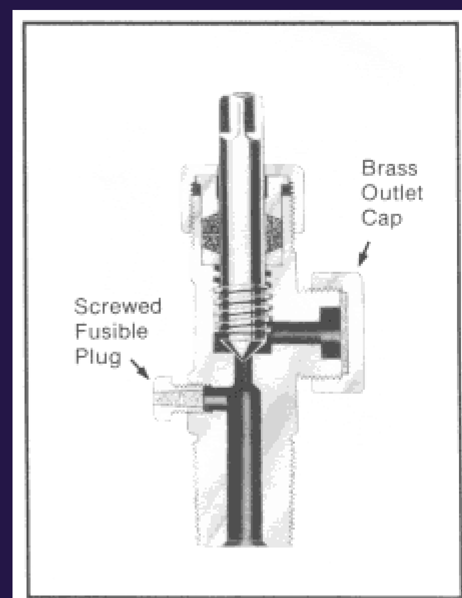
- Determine reagent blank
- Free residual testing contact time 60 seconds – 3 minutes
- Total residual testing contact time 3 – 6 minutes
- Regulatory minimum 0.2 mg/L at EP (SW)
- Looking for residual ≥ 0.2 mg/L after 24 hours (SW)
- DO NOT exceed the MRDL – maximum residual disinfectant level
  - 4 mg/L for chlorine, chloramines – CWS, NTNCWS
  - 0.8 mg/L for chlorine dioxide – TNCWS

Chlorine Operation and Maintenance


70° F
85 psi
85 %
full

Daily feed rates are not to be exceeded - freezing will occur.



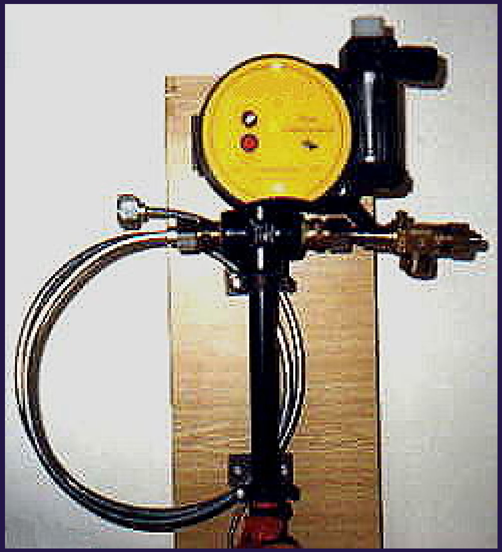

Brass
Outlet
Cap
Screwed
Fusible
Plug

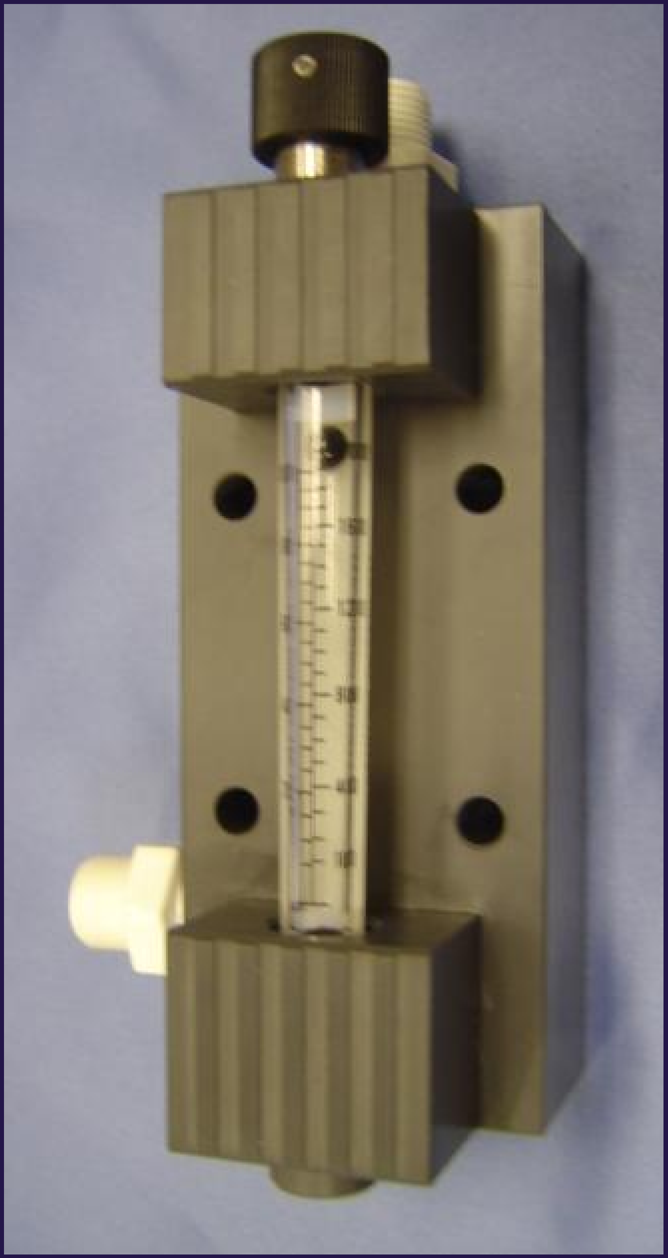
Chlorine/Sulfur Dioxide Leak Indicator Bottles

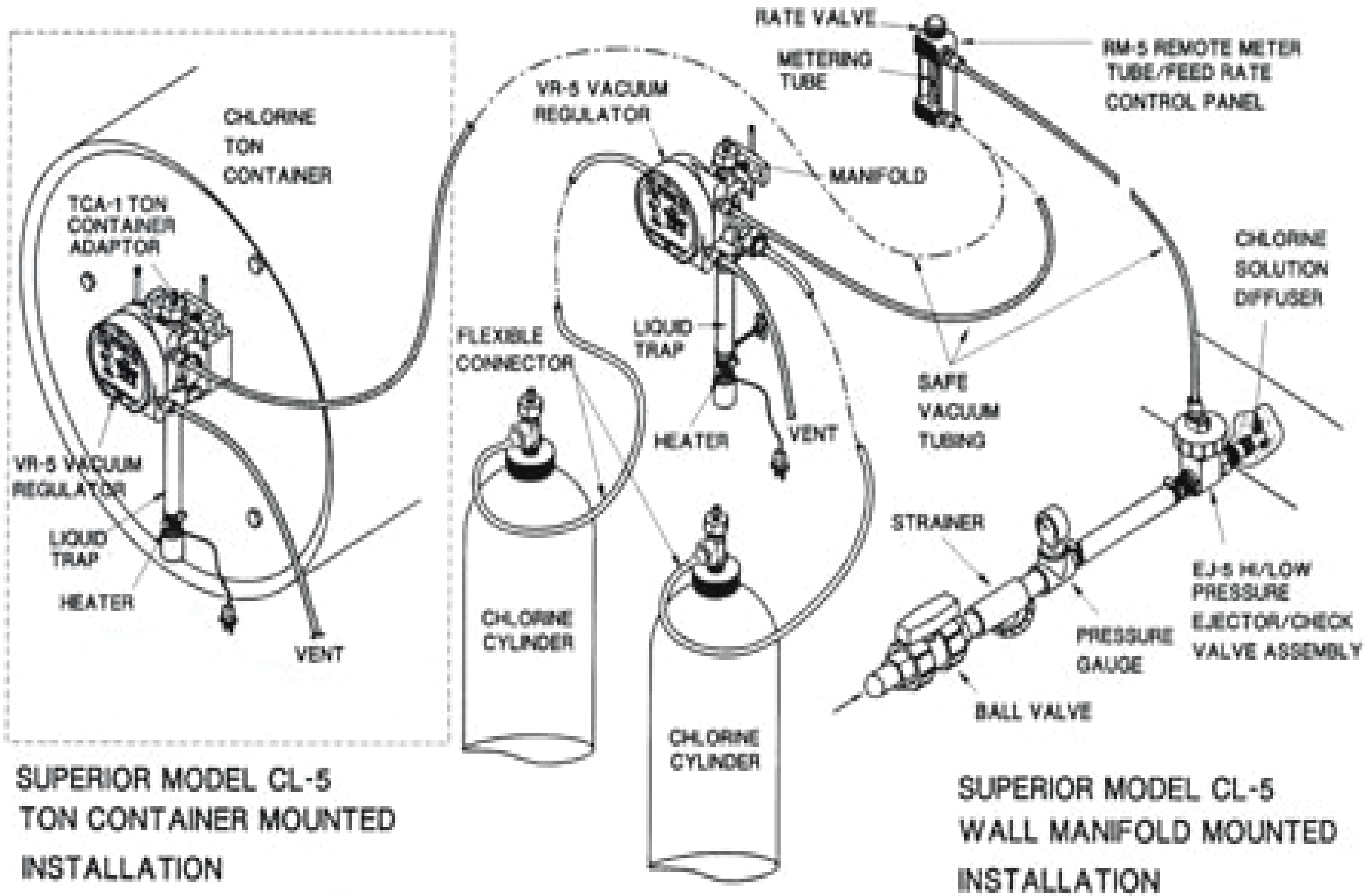
Chlorine and sulfur dioxide gas leaks can be easily & safely identified with ***aqueous ammonia vapor.*** Chlorine and sulfur dioxide safely react with ***ammonia*** to form a visible white cloud that identifies the source of the chemical leak.

Ammonia may cause problems with metal alloys. Anyone testing for chlorine leaks with ammonia water (ammonia hydroxide solutions) on brass or copper alloys must take care ***that only the ammonia vapor and not the liquid solution comes into contact with the alloy.***

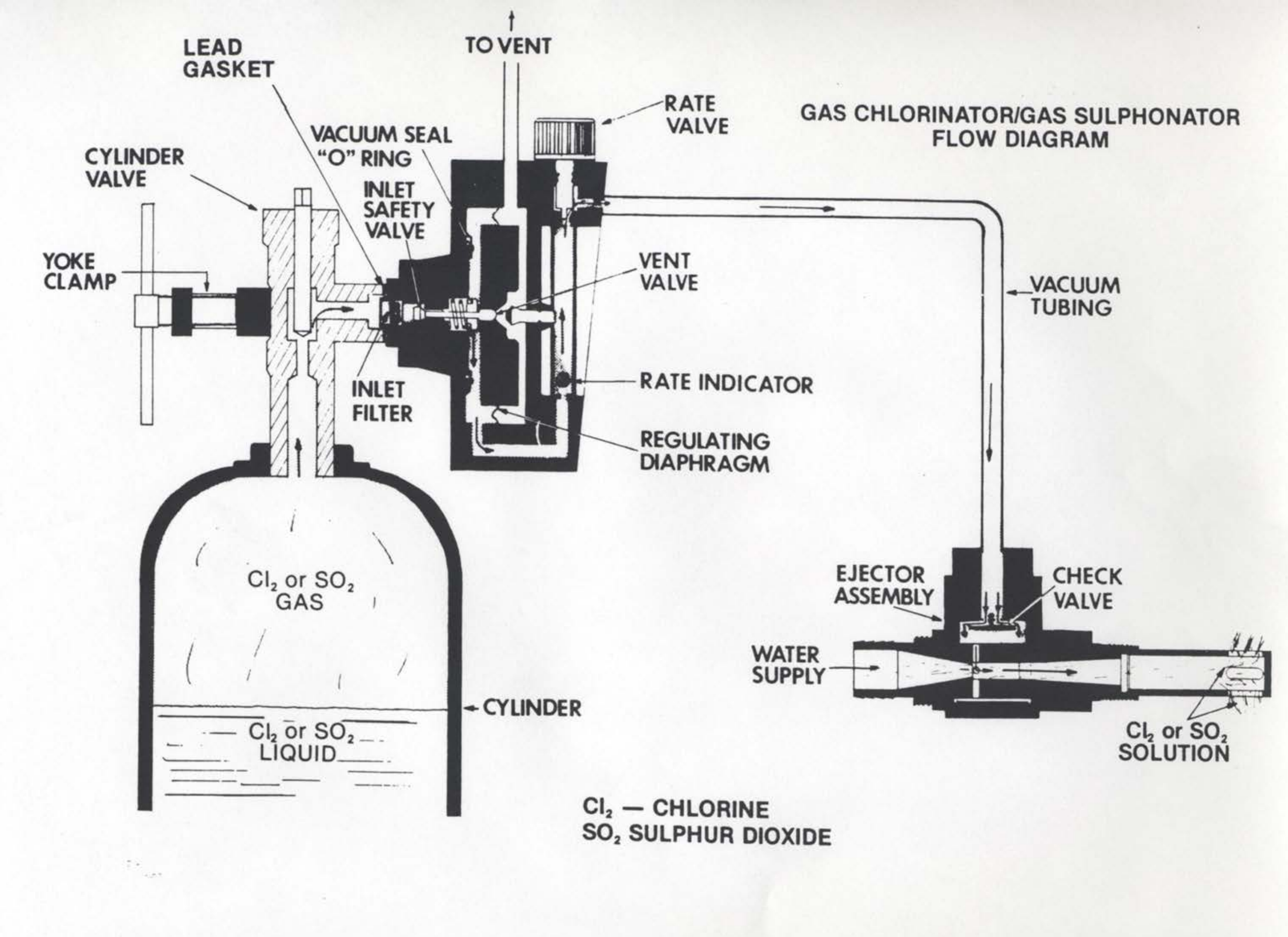

REGAL
chlorinators
incorporated







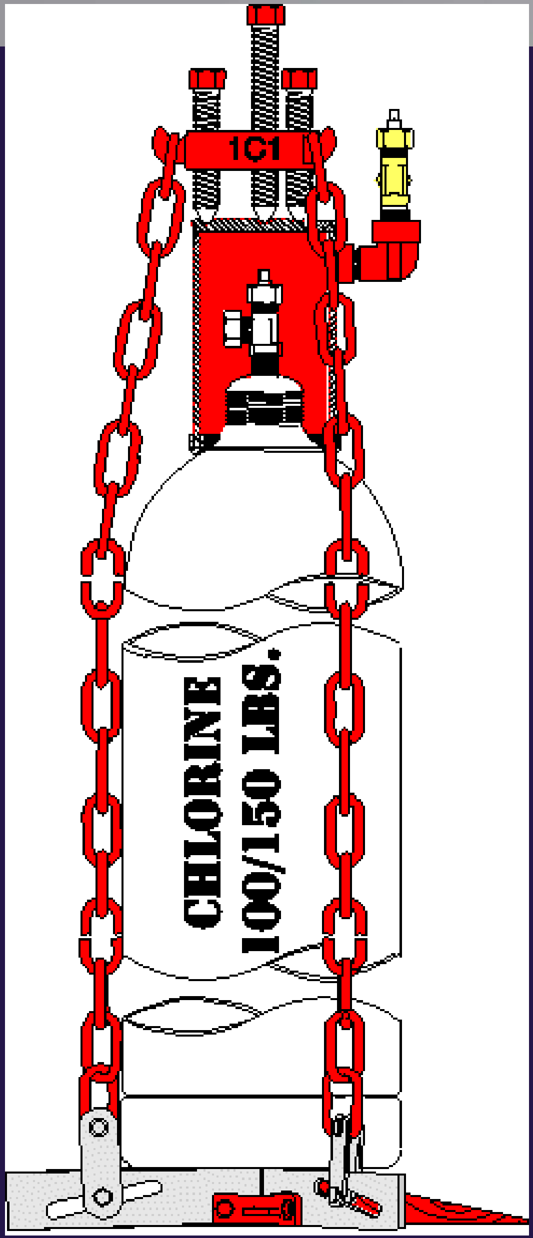
TYPICAL INSTALLATION


GAS CHLORINATOR/GAS SULPHONATOR FLOW DIAGRAM
TO VENT
LEAD GASKET
RATE VALVE
VACUUM SEAL "O" RING
CYLINDER VALVE
INLET SAFETY VALVE
YOKE CLAMP
VENT VALVE
VACUUM TUBING
RATE INDICATOR
INLET FILTER
REGULATING DIAPHRAGM
Cl_2 or SO_2 GAS
EJECTOR ASSEMBLY
CHECK VALVE
WATER SUPPLY
CYLINDER
Cl_2 or SO_2 LIQUID
Cl_2 or SO_2 SOLUTION
Cl_2 — CHLORINE
SO_2 SULPHUR DIOXIDE

Troubleshooting Gas Chlorinators

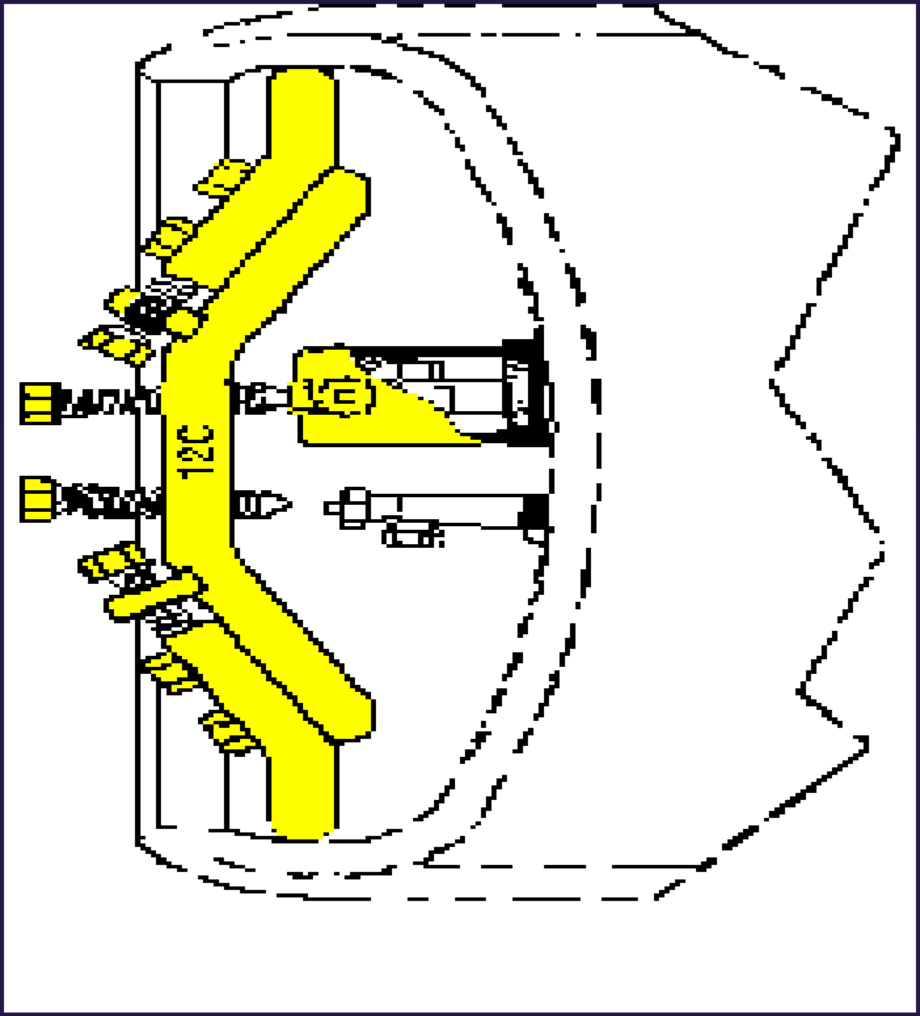
Symptom	Probable Cause
• Low Feed Rate and Low Vacuum	Clogged Injector/Ejector
• Low Feed Rate and High Vacuum	Clogged Gas Feed Line Closed Cylinder Valve Empty Cylinder
• Feed Rate Jumps	Clogged Flow Controller/Needle Valve
• Feed Rate Won't "Zero"	Dirty Flow Indicator/Rotameter
• Chlorine Gas at Vent	Dirty Pressure Regulating Valve
• No Vacuum	No Supply Water Vacuum Leak

Emergency Kit "A"
For 100 lb. and 150 lb. Chlorine Cylinders

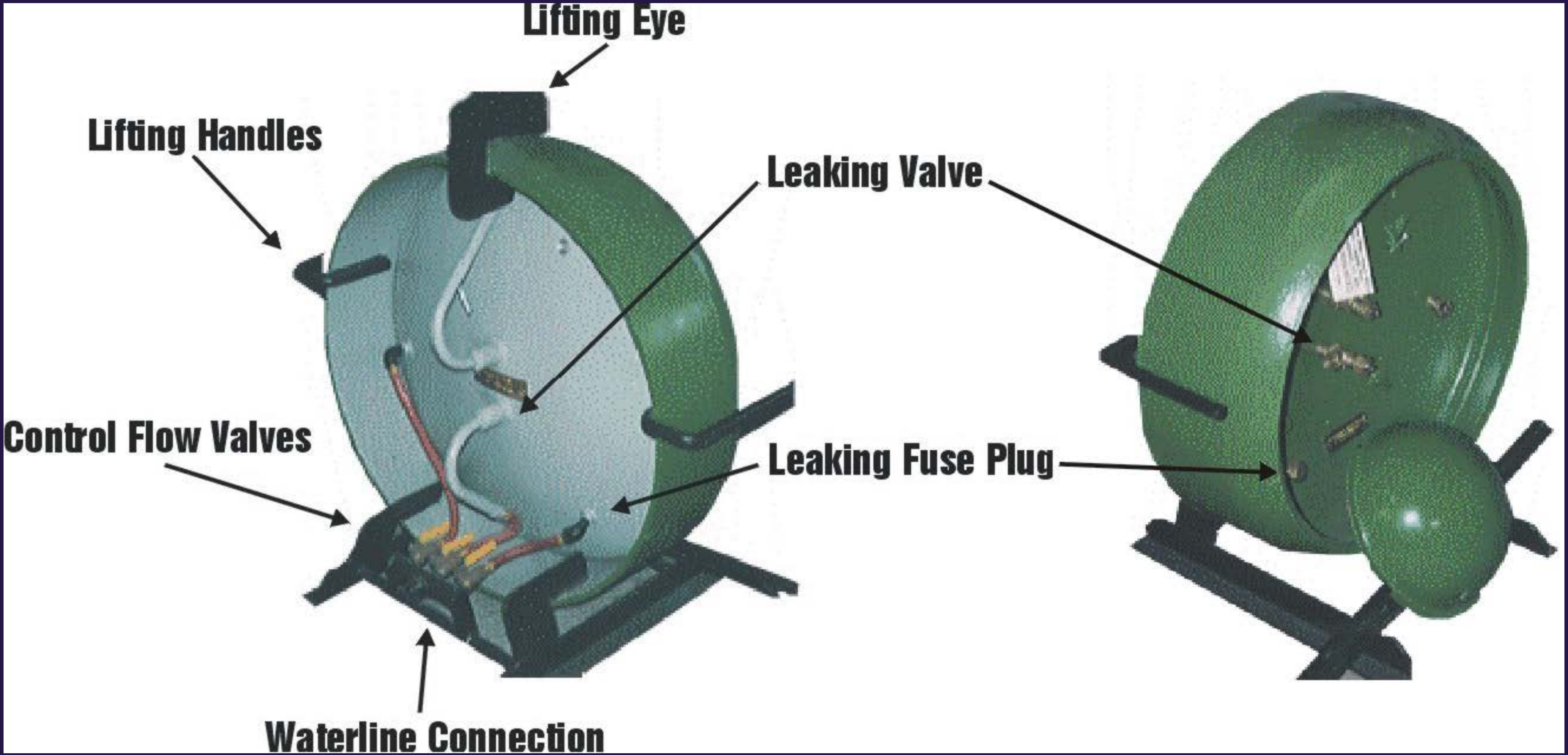

1C1
CHLORINE
100/150 LBS.


DOT E 9781
SALVAGE CYLINDER
CHLORINE
UN-1017-RQ

Emergency Kit "B"
For Chlorine 1-Ton Containers


12C

One Ton Cylinder



Powder Chlorine (Calcium Hypochlorite)

Calcium Hypochlorite $Ca(OCl)_2$

- Dry loose granular material
- Also comes in tablet form
- White or yellow-white in color
- Contains 65% - 70% available Cl_2 by weight
- Other 35% - 30% are binding compounds of lime
- Supports combustion

Liquid Chlorine (Sodium Hypochlorite Solution)

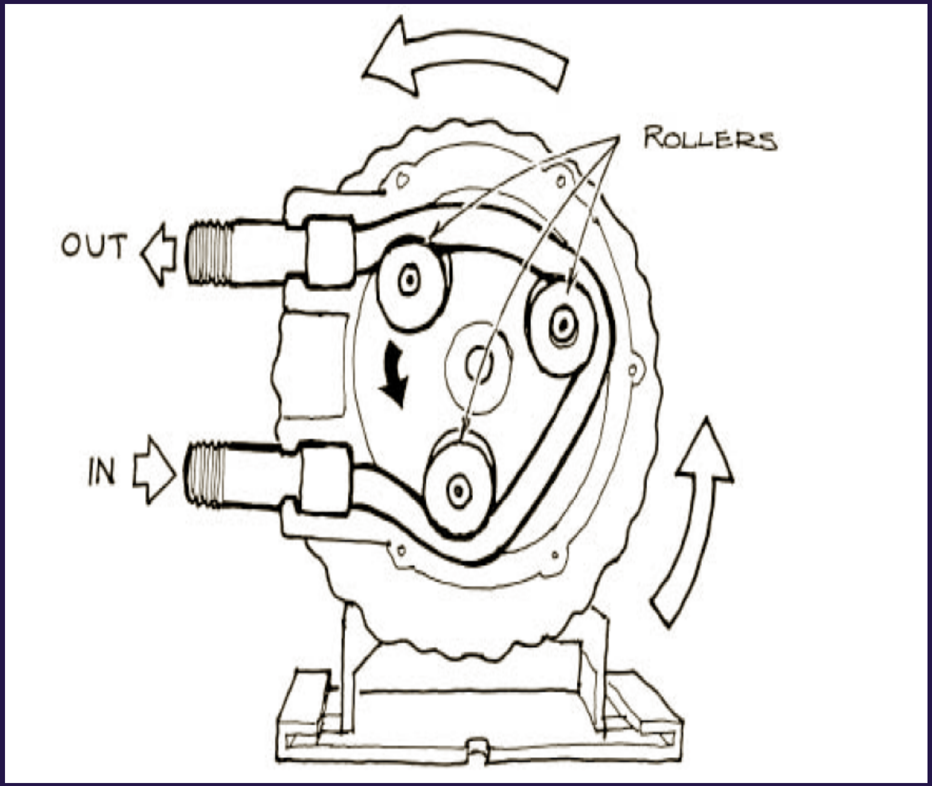
Sodium Hypochlorite (NaOCl)

- Clear to greenish-yellow liquid solution
- 9% - 15% available Cl_2
- No fire hazards are connected to NaOCl
- quite corrosive
- Reactive with other chemicals

Sodium hypochlorite generating unit, 0.8% available produced “Clor-Tec”

MIOX System

PERISTALTIC TYPE CHEMICAL FEED PUMP



Series 45 M – Adjustable Low Pressure: 0 to 25 psi (1.72 bar) Maximum Discharge Pressure

MODEL TUBE FEED RATE CONTROL SETTING: Outputs per day in U.S. Gallons @ 60Hz (black, left) & Liters @ 50Hz (green, right)

MODEL	TUBE	L		1		2		3		4		5		6		7		8		9		10	
45M1	#1	0.2	0.6	0.3	0.9	0.6	1.8	0.9	2.7	1.2	3.6	1.5	4.5	1.8	5.5	2.1	6.4	2.4	7.3	2.7	8.2	3.0	9.1
45M2	#2	0.5	1.5	1.0	3.0	2.0	6.1	3.0	9.1	4.0	12.1	5.0	15.1	6.0	18.2	7.0	21.2	8.0	24.2	9.0	27.3	10.0	30.3
45M3	#3	1.1	3.3	2.2	6.6	4.4	13.3	6.6	20.0	8.8	26.6	11.0	33.3	13.2	40.0	15.4	46.6	17.6	53.3	19.8	60.0	22.0	66.6
45M4	#4	1.7	5.1	3.5	10.6	7.0	21.2	10.5	31.8	14.0	42.4	17.5	53.0	21.0	63.6	24.5	74.2	28.0	84.8	31.5	95.4	35.0	106.0
45M5	#5	2.5	7.6	5.0	15.1	10.0	30.3	15.0	45.4	20.0	60.6	25.0	75.7	30.0	90.8	35.0	106.0	40.0	121.1	45.0	136.3	50.0	151.4

Series 45 MHP – Adjustable High Pressure: 0 to 100 psi (6.9 bar) Maximum Discharge Pressure

MODEL TUBE FEED RATE CONTROL SETTING: Outputs per day in U.S. Gallons @ 60Hz (black, left) & Liters @ 50Hz (green, right)

MODEL	TUBE	L		1		2		3		4		5		6		7		8		9		10	
45MHP2	#1	0.2	0.6	0.3	0.9	0.6	1.8	0.9	2.7	1.2	3.6	1.5	4.5	1.8	5.5	2.1	6.4	2.4	7.3	2.7	8.2	3.0	9.1
45MHP10	#2	0.5	1.5	1.0	3.0	2.0	6.1	3.0	9.1	4.0	12.1	5.0	15.1	6.0	18.2	7.0	21.2	8.0	24.2	9.0	7.3	10.0	30.3
45MHP22	#7	1.1	3.3	2.2	6.6	4.4	13.3	6.6	20.0	8.8	26.6	11.0	33.3	13.2	40.0	15.4	46.6	17.6	53.3	19.8	60.0	22.0	66.6

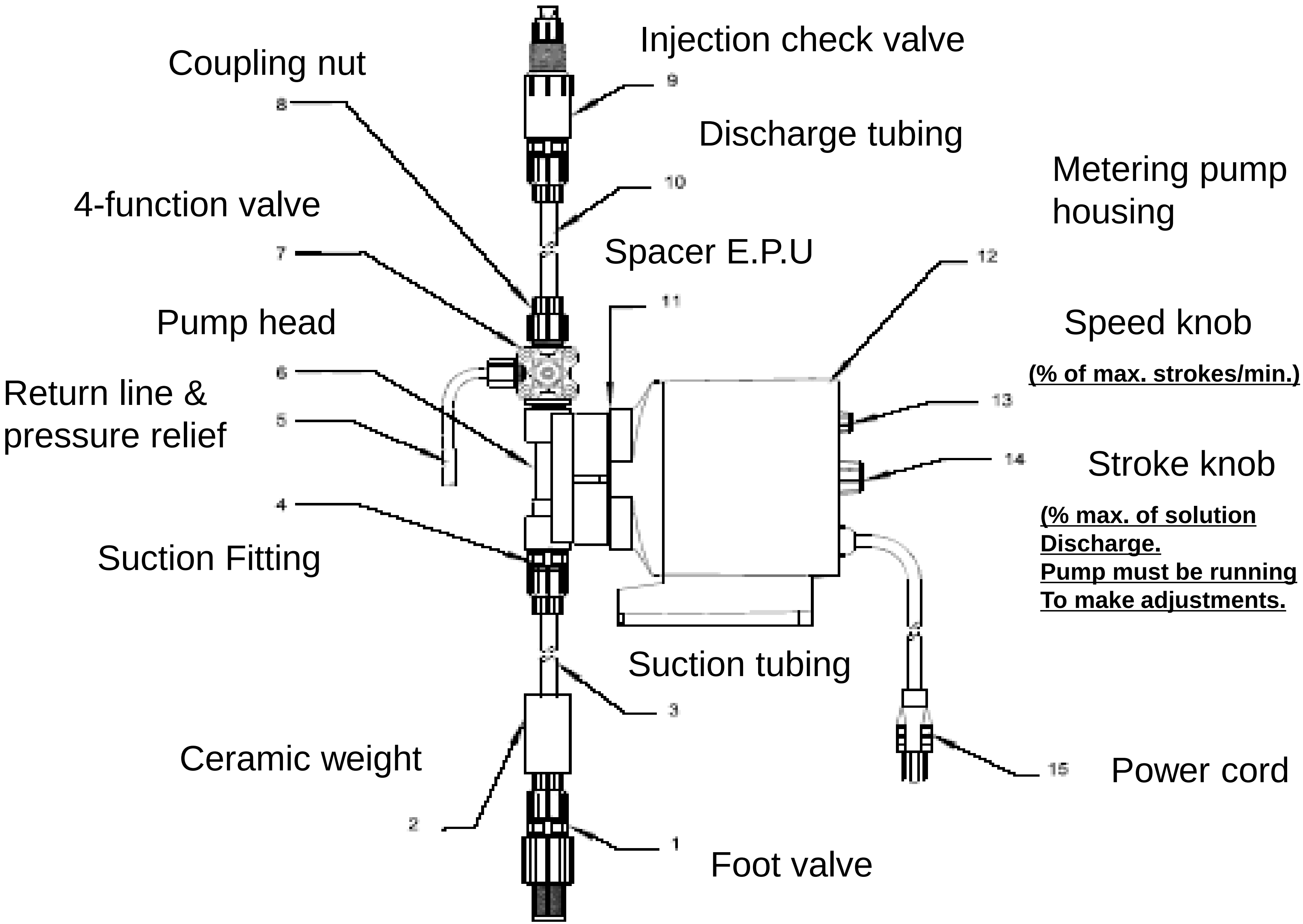
Series 45 MP – Fixed Rate Low Pressure: 0 to 25 psi (1.72 bar) Maximum Discharge Pressure

MODEL	PUMP TUBE	FIXED OUTPUT: U.S. Gals	Liters
45MP1	#1	3.0	9.1
45MP2	#2	10.0	30.3
45MP3	#3	22.0	66.6
45MP4	#4	35.0	106.0
45MP5	#5	50.0	151.4

Series 45 MPHP – Fixed Rate High Pressure: 0 to 100 psi (6.9 bar) Maximum Discharge Pressure

MODEL	PUMP TUBE	FIXED OUTPUT: U.S. Gals	Liters
45MPHP2	#1	3.0	9.1
45MPHP10	#2	10.0	30.3
45MPHP22	#7	22.0	66.6

Diaphragm Chemical Feed Pump Type



LMI Calculating Required Output

- Set-up & Installation

$$\frac{\text{Desired mg/L X GPM (Max Flow of Well Pump)}}{\text{\% Concentration of Chemical (Use \% as a decimal)}} \quad \text{X .006 (Conversion to GPH)}$$

= Required Pump Output in GPH

- Calculating output %

$$\frac{\text{Required Pump Output}}{\text{Maximum Output of Pump}}$$

= % Output Required from Pump

- Calculating % Speed & % Stoke

$$\sqrt{\text{\% Output Required from Pump}} \quad \text{(Square Root)}$$

= % Speed & % Stroke

Dechlorination

Physical or chemical removal of all residual chlorine prior to discharge to environment, accomplished using:

- Long detention times / Aeration / Sunlight
- Activated carbon
- Sulfur-based chemicals:
  - Sulfur dioxide - SO_2
  - Sodium sulfite - Na_2SO_3
  - Sodium bisulfite - $NaHSO_3$
  - Sodium thiosulfate - $Na_2S_2O_3$

Sulfur Chemical Dechlorination

- Sulfur dioxide - SO_2: Most common, frequently used
  - Reacts on 1:1 basis – 1mg/L SO_2 removes 1 mg/L chlorine residual
  - Solids, liquid or gas
  - Uses same type of equipment as gas chlorination; if using chlorine gas rotameter to measure SO_2 flow multiply reading by 0.95 to get pounds per day of SO_2 used (due to slight difference in density of the 2 gases)

Sulfur Dioxide Properties

- Colorless gas, pungent odor
- Chemical in any form is NOT flammable or explosive
- Gas can be cooled and compressed to a colorless liquid
- Under pressure, liquid and gas will stay in equilibrium
- Container pressure function of temperature
- Dry gas is not corrosive; in presence of moisture gas forms sulfuric acid – H_2SO_4 – not a pH factor unless alkalinity is very low
- Excessive dosage can reduce DO (and increase BOD) and decrease pH