Chemistry of Water Treatment

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Community Based Water Monitor and Operator Training

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Disinfection

- The purpose coagulation, flocculation, sedimentation and filtration is to prepare the water for disinfection
- Water can only be disinfected properly, if it is free of suspended matter which can hide or shield pathogens from the effects of the disinfectant

Chlorination

- Chlorination is the most common method of disinfection in Ontario, because chlorine:
  - Is effective at destroying most pathogens (bacteria and viruses)
  - Is inexpensive
  - Is readily available
  - Continues to disinfect the water long after it leaves the treatment plant (chlorine leaves a residual)

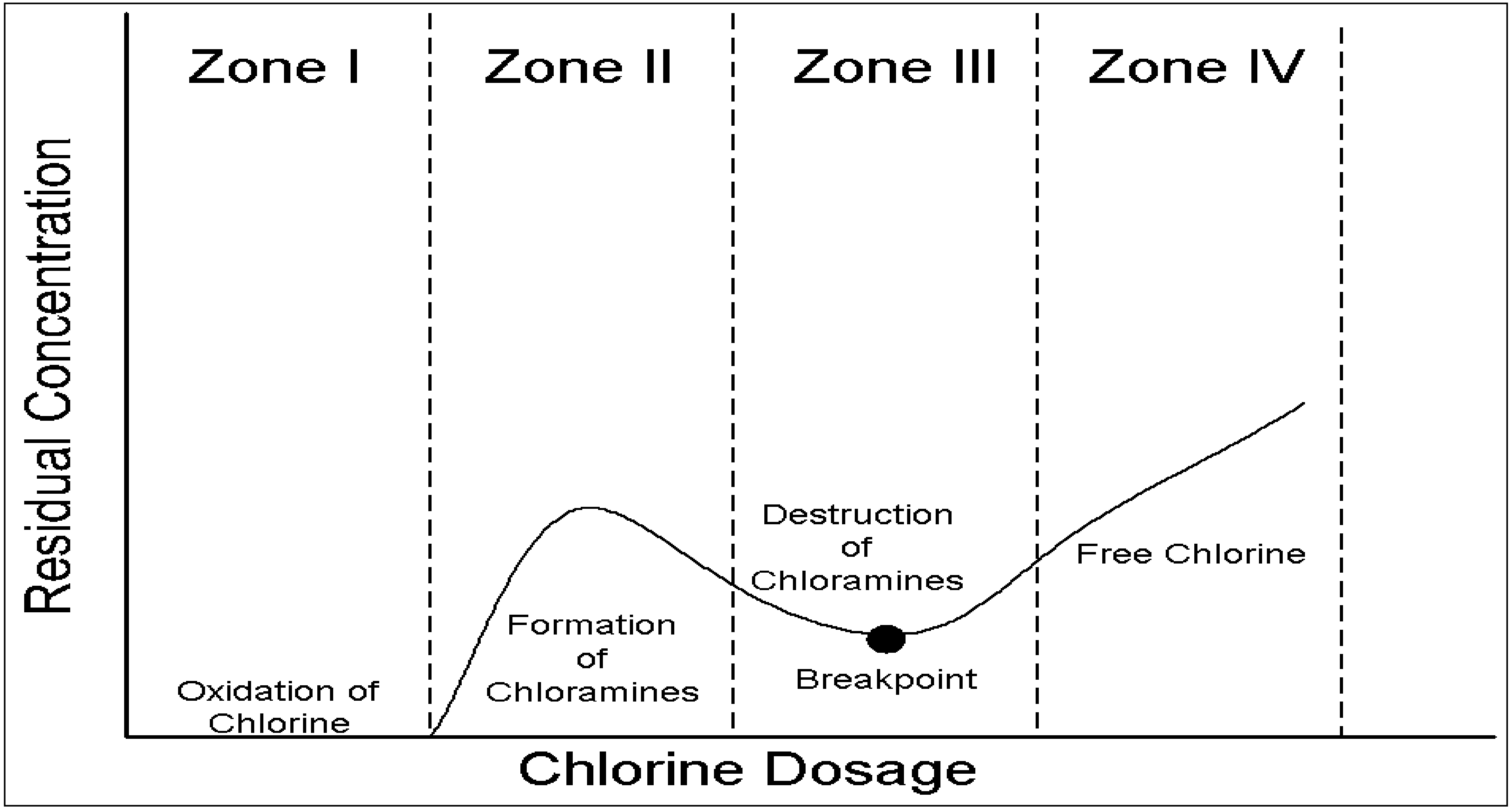
Chlorine - Forms

- Chlorine is typically available in one of three forms:
  - Liquid: Sodium Hypochlorite (10-12%)
  - Solid: Calcium Hypochlorite (65-70%)
  - Gas: Chlorine Gas (99.9%)

Chemistry of Chlorination

- When chlorine is added to water, it reacts with a wide variety of substances within the water
- The reactions that occur are usually shown on a graph, referred to as the “breakpoint chlorination curve” or “chlorine demand curve”

Breakpoint Chlorination Curve



Chlorine Residuals

- Two different types of chlorine residuals are used to disinfect water:
  - Free chlorine residuals
  - Combined chlorine residuals
- The type of chlorine residual used at any given treatment plant is dependant upon the specific conditions of that plant and distribution system

Free vs. Combined Chlorine Residuals

Free Chlorine	Combined Chlorine
• Kills faster, is more effective • Does not last as long • Reacts with organics to form THM's • Used for both primary and secondary disinfection	• Kills slower, is less effective • Lasts much longer • Does not react with organics to form THM's • Only used for secondary disinfection

Free Chlorine Residuals

- Free chlorine residuals are formed when chlorine is added to water containing little or no ammonia, or when chlorine is added in sufficient quantity to destroy any chloramines that were formed, as follows:

$$Cl_2 + H_20 \longrightarrow HCl + HOCl$$

chlorine + water → hydrochloric acid + hypochlorous acid

$$NaOCl + H_20 \longrightarrow NaOH + HOCl$$

sodium hypochlorite + water → sodium hydroxide + hypochlorous acid

$$Ca(OCl)_2 + 2H_20 \longrightarrow Ca(OH)_2 + 2HOCl$$

calcium hypochlorous hypochlorite acid + water → calcium hydroxide

Free Chlorine - Factors

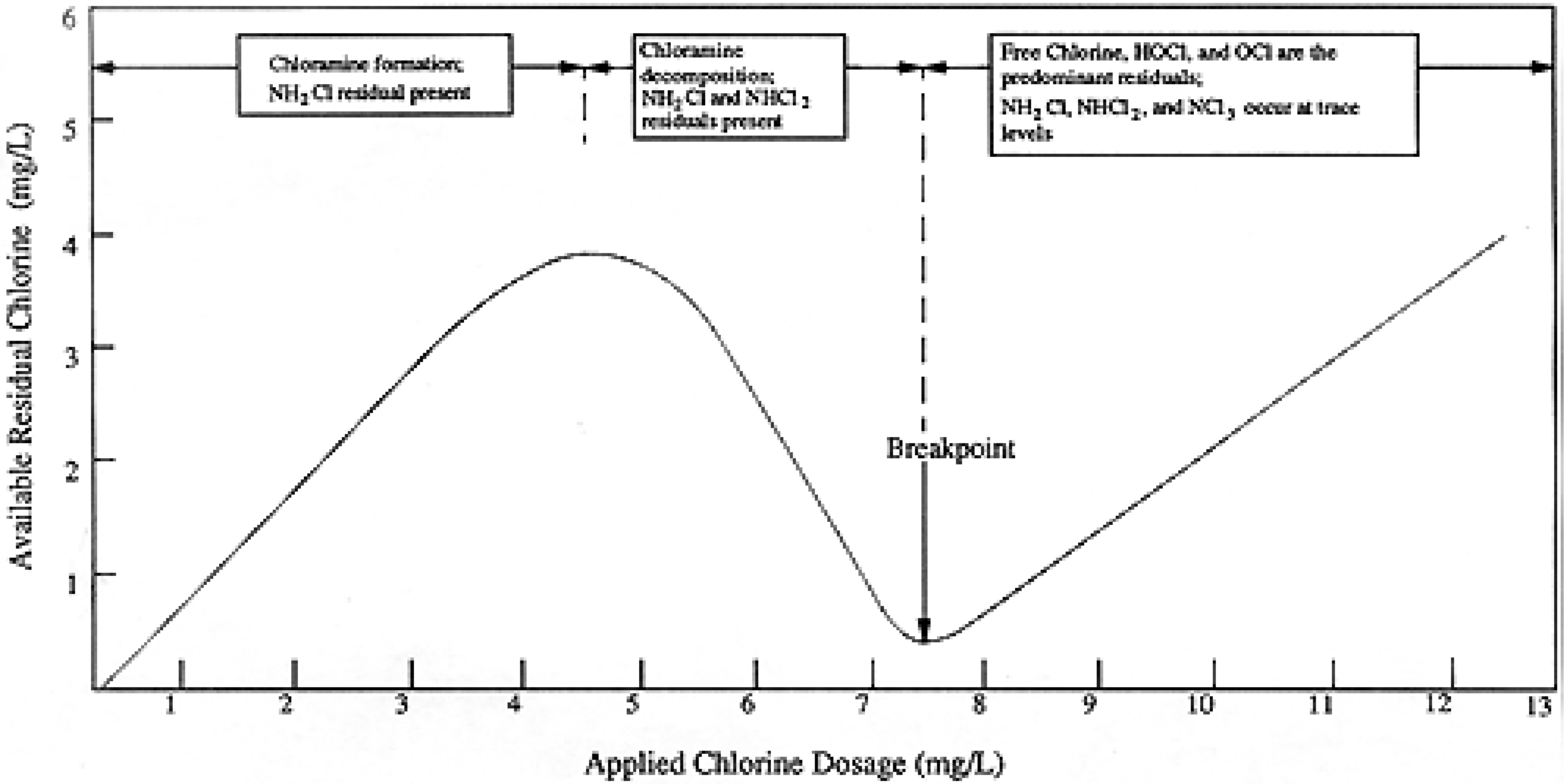
- The effectiveness of free chlorine is dependant upon the following factors:
  - Presence of interfering/reducing substances
  - Concentration of chlorine
  - Contact time
  - Water temperature
  - pH

Combined Chlorine Residuals

- **Combined chlorine residuals are formed when chlorine is added to water containing ammonia, as follows:**

$HOCl$ hypochlorous acid	+	NH_3 ammonia	→	NH_2Cl monochloramines	+	H_2O water
NH_2Cl monochloramines	+	$HOCl$ hypochlorous acid	→	$NHCl_2$ dichloramines	+	H_2O water
$NHCl_2$ dichloramines	+	$HOCl$ hypochlorous acid	→	NCl_3 trichloramines	+	H_2O water

Chloramination
Chlorine : Ammonia



Source: Wolfe et al. 1984

Figure 3.6 Theoretical breakpoint chlorination scheme (1.0 mg/L ammonia-nitrogen; pH 7; temperature 25°C; contact time 2 hours)

NOTE: Monochloramines production is optimal at a 3.0 : 1.0 to 4.5 : 1.0 ratio

Disinfection By-Products

- The two most common disinfection by-products of free chlorine are trihalomethanes (THMs) and haloacetic acids (HAAs)
- Both are formed as a result of the reaction between free chlorine and natural organic matter (precursors)
- These DBP are suspected human carcinogens (cause cancer)

THMs

- There are four types of THMs formed when free chlorine reacts with organic matter:
  - Chloroform
  - Bromoform
  - Dichlorobromomethane
  - Dibromochloromethane

THMs

- THMs are currently regulated in Ontario
- The maximum acceptable concentration is 0.100 mg/L based on the annual running average of quarterly samples
- The MAC of 0.100 mg/L will be reduced to 0.080 mg/L within the next two years
- THM samples must be collected from a location within the distribution system which is likely to have an elevated concentration of THMs

HAAs

- Many different types of HAAs are formed when free chlorine reacts with organic matter
- Five of these are currently regulated in the United States:
  - Monochloroacetic acid
  - Dichloroacetic acid
  - Trichloroacetic acid
  - Monobromoacetic acid
  - Dibromoacetic acid

Factors - DBP Formation

- Type and amount of NOM
- Chlorine application point
- Chlorine concentration
- Contact time
- Temperature
- pH

Alternative Disinfectants

- The use of alternative disinfectants has been fueled by:
  - Concerns over disinfection by-products
  - Research indicating that some pathogens show more resistance to some disinfectants than to others

Ozone

- Is a very unstable gas that must be generated on-site
- Is formed by passing oxygen through electrodes
- High voltage to the electrodes causes an electrical arc to form
- As oxygen (O_2) passes through the electrical arc it is broken down and fused back together as ozone (O_3)

Ozone

- Only 8-14 % of the oxygen will be converted into ozone
- Electrical consumption is high, making ozone more expensive than chlorine
- Does not produce a residual that persists in the water (can only be used for primary disinfection)
- Produces disinfection by-products (bromoform and bromate)

Ultraviolet Light

- Is generated by mercury or antimony vapour lamps in a protective quart sleeve
- Is a physical disinfection process, not dependant upon water chemistry (pH)
- Does not produce disinfection by-products

Ultraviolet Light

- Quartz sleeve may become coated and must be cleaned periodically
- Water must pass very close to UV light source to be disinfected properly
- Sensitive to the presence of particulate matter
- Light intensity must be closely monitored
- Sensitive to flow rates, velocity (contact time)
- Does not leave a residual, can only be used for primary disinfection

Chlorine Dioxide

- Is a greenish-yellow gas with strong chlorinous odour
- Is unstable and must be generated on-site
- Is formed by reacting sodium chlorite with chlorine gas
- May not react completely and may leave disinfection by-products (chlorite and chlorate)
- Strong odour above 0.5 mg/L
- Is limited to a maximum dose of 1.0 mg/L

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Questions?

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