Lecture 7: Disinfection

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7. Disinfection in water Treatment

7.1 Definition of Disinfection:

Disinfection is the destruction of pathogenic microorganisms.

7.2 Disinfection methods:

A. Chemical disinfection:
   - Chlorination
   - Ozonation

B. Non chemical disinfection:
   - Heat
   - Ultra Violet radiation (UV)
7.3  **Definition Microorganisms of concern include:**

Microorganisms of concern include:

<table>
<thead>
<tr>
<th>Type</th>
<th>Size, μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viruses</td>
<td>0.01 to 0.1</td>
</tr>
<tr>
<td>Bacteria</td>
<td>0.1 to 5</td>
</tr>
<tr>
<td>Cryptosporidium oocysts</td>
<td>3 to 5</td>
</tr>
<tr>
<td>Giardia cysts</td>
<td>6 to 10</td>
</tr>
<tr>
<td>Protozoan</td>
<td>10 to 25</td>
</tr>
</tbody>
</table>

- **Indicator organisms are often used to assess the presence or absence of pathogens**
- **Common indicator organisms are coliforms-E-coli**
7.4 Disinfection by chlorination

7.4.1 Introduction on Chlorination:

- Chlorine is the most widely used disinfectant because it is effective at low concentrations, cheap and forms residual if applied in sufficient dosage.
- The principal chlorine compounds used in water treatment are:
  * Chlorine (Cl\textsubscript{2}),
  * Sodium hypochlorite (NaOCl),
  * Calcium hypochlorite [Ca(OCl)\textsubscript{2}], and
  * chlorine dioxide (ClO\textsubscript{2}).
- Chlorine (Cl\textsubscript{2}) can be used in gas or liquid form.
- The Cl\textsubscript{2} gas is liquefied by high pressure (5-10 atm) to the liquid form.
7.4 Disinfection by chlorination

7.4.2 Chemistry of Chlorine in water:

- Chlorine gas reacts readily with water to form hypochlorous acid and hydrochloric acid:
  \[ \text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HOCl} + \text{HCl} \]

- The produced hypochlorous acid then dissociates to yield hypochlorite ion:
  \[ \text{HOCl} \rightarrow \text{H}^+ + \text{OCl}^- \]

- The relative distribution of HOCl and OCl\(^-\) is a function of pH and temperature. See (Fig 7.1). Both HOCl and OCl\(^-\) are excellent disinfectants but HOCl is more effective.

- Both HOCl & OCl\(^-\) react with ammonia if exists in water to produce chloramines:
  \[ \text{NH}_3 + \text{HOCl} \rightarrow \text{NH}_2\text{Cl} + \text{H}_2\text{O} \quad \text{(monochloramine)} \]
  \[ \text{NH}_2\text{Cl} + 2\text{HOCl} \rightarrow \text{NHCl}_2 + \text{H}_2\text{O} \quad \text{(dichloramine)} \]
  \[ \text{NHCl}_2 + 3\text{HOCl} \rightarrow \text{NCl}_3 + \text{H}_2\text{O} \quad \text{(Trichloramine)} \]

  **Note:** Chloramines are good disinfectants

- Both HOCl & OCl\(^-\) react with reducing compounds such as Fe\(^{+2}\), Mn\(^{+2}\), NO\(^{-2}\), and the chlorine will be reduced to the non effective chlorid ion Cl\(^-\).
Figure 7.1  Relative amount of HOCl and OCl⁻ as a function of pH at 0° and 20°.
Both HOCl & OCl react with reducing natural organic matters producing trihalomethanes (THMs) including:
- Chloroform (CHCl₃),
- Bromoform (CHBr₃),
- Bromodichloromethane (CHCl₂Br),
- Dibromochloromethane (CHClBr₂).

The THMs are carcinogenic compounds and their total concentration in drinking water should not be more than 0.1 mg/l.

THMs are one of the disinfection by products DBPs that should be minimized or removed before supplying the water to the consumers. Another dangerous DBPs is the halogenated acetic acids HAAs as it may cause cancer. THMs and HAAs can be minimized by removing the organic matter before disinfection. THMs and HAAs can be removed from water by GAC.
7.4 Disinfection by chlorination

7.4.3 Break point chlorination:

- As illustrated in the previous section, chlorine reacts with the substances existing in water. Figure 7.2 shows the stages of these reactions.
- On Fig 7.2, The chlorine dosage is presented on the x-axis and the residual chlorine is presented on the y-axis.
- When chlorine is added it reacts first with the reducing compounds such as Fe\(^{+2}\), Mn\(^{+2}\), NO\(^{-2}\), and the chlorine will be reduced to the none effective chloride ion Cl\(^{-}\) (from zero to point A on the figure).
- When adding more chlorine it will react with NH\(_3\) to form chloramines as shown in the chlorine chemistry (from point A to B).
- When adding more chlorine some chloramines are oxidized to nitrogen gas and the chlorine is reduced to the none effective Cl\(^{-}\) ion. (from point B to C).
- Continued addition of chlorine will produced free available chlorine (at point C). Point C is called the break point.
7.4 Disinfection bychlorination
7.4 Disinfection by chlorination

- The chlorine added is called the dosage.
- The amount used to oxidize the materials existing in water is called the demand.
- The Free residual = dosage – demand
- The residual between points A to C is called combined residual because the chlorine is in the form of chloramines and chloro-organics.
- From point C and up a free residual chlorine start to appear in water in addition to the combined residual.
- The free Chlorine residual is composed of un-reacted forms of chlorine HOCl and OCl⁻.
- The total residual after the break point = free + combined.
- Since the free residual is much more effective in disinfection, all the regulations require a free residual of at least 0.20 mg/l at the farthest tap in the system. The residual chlorine in the produced water is typically 2 – 5 mg/l just at the outlet of the treatment.
- Since free residual appears only after the breakpoint, so we need to decide the breakpoint dosage. Thus the required dosage = breakpoint dosage + free residual.
Example 7.1:
Referring to the Figure, if a dosage of 1.8 mg/L is applied, determine:
(1.) The amount free chlorine residual (2.) The amount of combined residual,
(3.) The amount of total residual, (4.) What is the chlorine demand?

[Diagram showing the relationship between chlorine added (mg/L) and chlorine residual (mg/L)]
From the figure:

1. The of free chlorine residual at a dosage of 1.80 mg/L = 0.40 mg/L.

2. The combined residual at the breakpoint = 0.21 mg/L.

3. The Total residual = 0.40 + 0.21 mg/L = 0.61 mg/L.

4. Chlorine demand = 1.40 mg/L
7.4 Disinfection by chlorination

7.4.4 CT concept:

- The chlorination efficiency is determined using the CT value.
- \( C \) = Free residual chlorine concentration in the chlorination tank, mg/L
  \( T \) = contact time in the storage tank, min.
- The chlorination efficiency is determined according to the value \( C \times T \)
- See the USEPA Table for the required values of CT to achieve certain value of microorganisms inactivation.
- For example, a CT value of 67 (min*mg/L) is needed at 20 °C and a pH of 7.5 and a residual chlorine of 1 mg/L to achieve \textbf{3 log inactivation} of Giardia cysts. In this case \( T = \frac{67}{1} = 67 \) min.
- The disinfection is achieved inside the chlorination tank. To increase the contact time or (the detention time) in the tank, baffle walls are usually used. This will increase the CT value available in the tank and achieve the design CT value.
**Illustration of the inactivation units**

\[
10^n \log \text{inactivation} = \frac{N_0}{N_r}
\]

Or \[n \ Log \ Inactivation = \log N_0 - \log N_r\]

Where,

\(n = \text{number of log inactivation}\)

\(N_0 = \text{initial concentration of microorganism in water, Cells/100ml (before treatment)}\)

\(N_r = \text{Remaining concentration of microorganism in water, Cells/100ml (A after treatment)}\)
Example 7.2

The Initial number of Gardia cysts in water is $= 10^6$ Cell/100 ml. Calculate the nlog inactivation for the given remaining concentration at each inactivation logs.

A ) $N_r = 10^4$

$n \text{Log Inactivation} = \log N_0 - \log N_r$

$= \log 10^6 - \log 10^4$

$= 6 - 4 = 2 \text{ log inactivation}$

B ) $N_r = 2.3 \times 10^3$

$n \text{Log Inactivation} = \log N_0 - \log N_r$

$= \log 10^6 - \log (2.3 \times 10^3)$

$= 6 - 3.362 = 2.638 \text{ log inactivation}$
7.4 Disinfection by chlorination

7.4.5 Predicting chlorination efficiency:

The efficiency of chlorination can be predicted using Chick’s Watson formula:

\[
\frac{N_t}{N_0} = e^{-k'C^n t}
\]

- \( k' \) = die– off constant
- \( C \) = concentration of des infectant, \( mg/L \)
- \( n \) = coefficient of dilution
- \( N_t \) = number of organisms at time \( t \), \( Cell/100ml \)
- \( N_0 \) = initial number of organisms, \( Cell/100ml \)
- \( t \) = contact time, min
7.4 Disinfection by chlorination

7.4.5 Predicting chlorination efficiency:

Example 7.3:
The concentration of Giardia cysts in drinking water is $10^4/100$ ml. A free chlorine Residual of 1.2 mg/L has been created in the chlorination tank. The detention time in the chlorination tank is 57 min. What is the final concentration of Giardia cysts? What is the Inactivation percent and the Log- inactivation in this case? Take $n = 1.0$, and $k = 0.103$.

\[
\frac{N_t}{N_0} = e^{-0.10 \times 1.2 \times 57} = e^{-0.684} = 1.07 \times 10^{-3}
\]

\[
N_t = 10^4 \times 1.07 \times 10^{-3} = 10.7 \text{ Cells} / 100 \text{ml}
\]

\[
\text{Percent inactivation} = \frac{N_0 - N_t}{N_0} = \frac{10^4 - 10.7}{10^4} \approx 0.999 = 99.9\%
\]

\[
n \log \text{ inactivation} = \log 10^4 - \log 10.7 = 2.97 \text{ Log inactivation}
\]

\[
N_{\text{removed}} = N_0 - N_t = 10^4 - 10.7 = 9989 \text{ Cell} / 100 \text{ml}
\]

\[
N_{\text{removed}} = N_0 \left(1 - \frac{1}{10^n \log \text{ inactivation}}\right) = 10^4 \left(1 - \frac{1}{10^{2.97}}\right) = 9989 \text{ Cell} / 100 \text{ml}
\]