Water Treatment Design
Lecture-13
Chlorination

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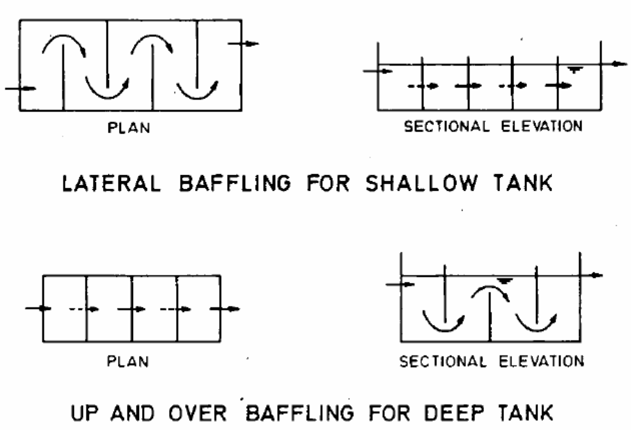


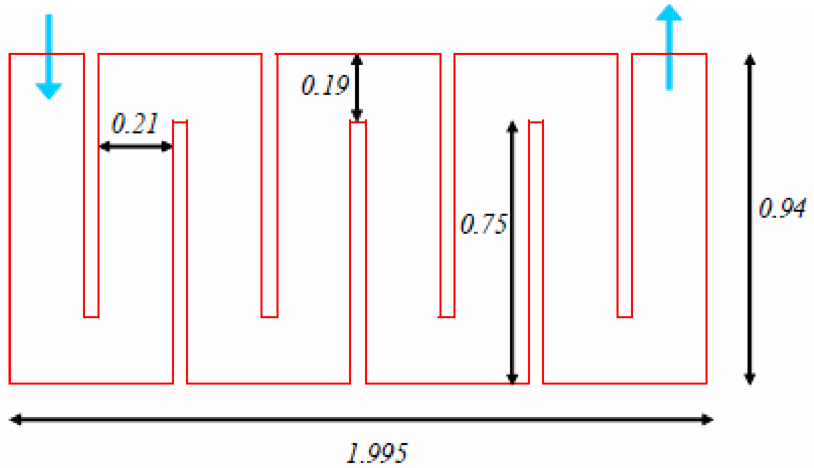


Figure.1. Plan view of original contact tank

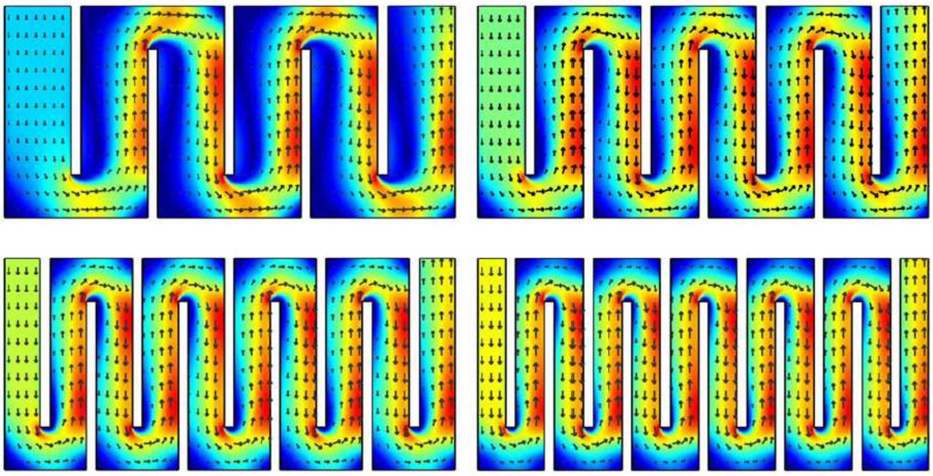


Figure.2. Simulated flow field and velocity vectors in the tanks with 5, 7, 9 and 11 baffles

CHLORINE CONTACT TIME CALCULATIONS

Ref:http://hawaii.gov/health/environmental/water/sdwb/sdwb/pdf/CT_Calc_Examples.pdf

Equations:

$$Total\ detention\ time = \frac{Lowest\ operating\ volume}{Peak\ flow}$$

The operating volume should be taken during peak hour demand but the lowest operating volume may be substituted with Safe Drinking Water Branch's approval.

$$Contact\ time = Total\ detention\ time \times Baffling\ factor$$

$$CT\ calc = Residual\ chlorine\ concentration \times Contact\ time$$

$$Inactivation\ Ratio = \frac{CTcalc}{CTreq}$$

$$4log\ virus\ inactivation\ check: Inactivation\ ratio \times 4\ \geq 4 \rightarrow OK!$$

$$4log\ virus\ inactivation\ check: Inactivation\ ratio \times 4\ < 4 \rightarrow Rework\ Calculated\ Parameters$$

Table 3-2 – Baffling Factors

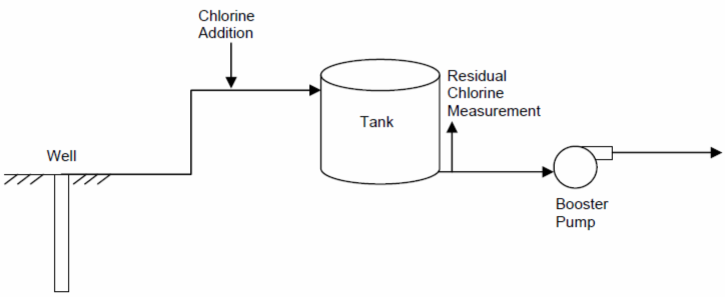
Factor	Description
0.1	None, agitated basis, very low length to width ratio, high inlet and outlet flow velocities. Enclosed circular or rectangular tank with single inlet and outlet line. Enclosed circular or rectangular tank with inlet on top and outlet on the bottom, either directly below or on the same side as the inlet line.
0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles. Enclosed circular or rectangular tank with inlet on top and outlet on the bottom on the opposite wall.
0.5	Baffled inlet or outlet with some intra-basin baffles.
0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders.
1	Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intra-basin baffles.

Table B-2 – CTreq values for 4-log virus inactivation of viruses by free chlorine in mg/L•min

Temperature (°C)	pH	
	6-9	10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

1. Is the water system providing 4log virus inactivation using 12.5% sodium hypochlorite?

GIVEN



Well capacity = 100 gpm
Residual chlorine concentration = 0.1 mg/L free chlorine, measured at the outlet of the tank
Tank's total capacity = 50,000 gallons
Tank's lowest operating volume = 25,000 gallons
Booster pump capacity = 250 gpm
Tank has no baffles with a separate inlet and outlet. The inlet is located at the top of the tank and the outlet is located at the bottom of the tank on the opposite wall.
pH = 7.5
Temperature = 20°C

FIND If the water system is providing 4-log virus inactivation.

NOT RELEVANT
- The well capacity has no bearing on the peak flow of the water system.
- Using the tank's total capacity will increase the results and not cover the most conservative situation when the tank is at its lowest operating volume.

SOLUTION

From Table 3-2, Baffling factor = 0.3.
From Table B-2, CT req = $3\,\frac{mg}{L}\cdot min$
Peak Flow = 250 gpm

$$Total\ detention\ time = \frac{Lowest\ Operating\ Volume}{Peak\ flow}$$

$$Total\ detention\ time = \frac{25{,}000\ gallons}{250\ \frac{gal}{min}}$$

$$Total\ detention\ time = 100\ min$$

$$Contact\ time = Total\ detention\ time \times Baffling\ factor$$

$$Contact\ time = 100\ min \times\ 0.3$$

$$Contact\ time = 30\ min$$

$$Contact\ time = 30\ min$$

$$CTcalc = Residual\ chlorine\ concentration \times Contact\ time$$

$$CT\ calc = 0.1\ \frac{mg}{L} \times 30\ min$$

$$CT\ calc = 3\ \frac{mg}{L}\cdot min$$

$$Inactivation\ ratio = \frac{CT\ calc}{CT\ req}$$

$$Inactivation\ ratio = \frac{3\ \frac{mg}{L}\cdot min}{3\ \frac{mg}{L}\cdot min}$$

$$Inactivation\ ratio = 1$$

$$4log\ virus\ inactivation\ check = Inactivation\ ratio \times 4$$

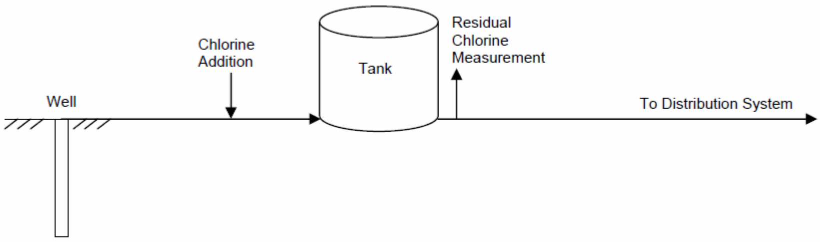
$$4log\ virus\ inactivation\ check = 1 \times 4$$

$$4log\ virus\ inactivation\ check = 4$$

$4log\ virus\ inactivation\ check\ \geq 4, therefore, 4log\ virus\ inactivation\ is\ achieved!$ Answer: YES

2. Is the water system providing 4log virus inactivation using 12.5% sodium hypochlorite?

GIVEN



Well capacity = 600 gpm
Residual chlorine concentration = 0.1 mg/L free chlorine, measured at the outlet of the tank
Tank's total capacity = 600,000 gallons
Tank's lowest operating volume = 200,000 gallons
Peak hour flow = 1,200 gpm
Tank has no baffles with a separate inlet and outlet with high inlet and outlet flow velocities.
pH = 6.8
Temperature = 25°C

FIND If the water system is providing 4-log virus inactivation.

NOT RELEVANT
- The well capacity has no bearing on the peak flow of the water system.
- Using the tank's total capacity will increase the results and not cover the most conservative situation when the tank is at its lowest operating volume.

SOLUTION

From Table 3-2, Baffling factor = 0.1
From Table B-2, CT req = 2 $\frac{mg}{L} \cdot min$
Peak flow = 1,200 gpm

$$Total\ detention\ time = \frac{Lowest\ Operating\ Volume}{Peak\ flow}$$

$$Total\ detention\ time = \frac{200{,}000\ gallons}{1{,}200\ \frac{gal}{min}}$$

$$Total\ detention\ time = 166.67\ min$$

$$Contact\ time = Total\ detention\ time \times Baffling\ factor$$

$$Contact\ time = 166.67\ min \times\ 0.1$$

$$Contact\ time = 16.67\ min$$

$$CTcalc = Residual\ chlorine\ concentration \times Contact\ time$$

$$CT\ calc = 0.1\ \frac{mg}{L} \times 16.67\ min$$

$$CT\ calc = 1.67\ \frac{mg}{L} \cdot min$$

$$Inactivation\ ratio = \frac{CT\ calc}{CT\ req}$$

$$Inactivation\ ratio = \frac{1.67\ \frac{mg}{L} \cdot min}{2\ \frac{mg}{L} \cdot min}$$

$$Inactivation\ ratio = 0.84$$

Round to 1 decimal place.

$$Inactivation\ ratio = 0.8$$

$$4log\ virus\ inactivation\ check = Inactivation\ ratio \times 4$$

$$4log\ virus\ inactivation\ check = 0.8 \times 4$$

$$4log\ virus\ inactivation\ check = 3.6$$

$4log\ virus\ inactivation\ check\ < 4, therefore, 4log\ virus\ inactivation\ is\ \textbf{not}\ achieved!$

Answer: NO

Sentetik Organikler

(DBPs) : Dezenfeksiyon Yan Ürünleri

Klorlamanın yan ürünleri:

THMs : Trihalo Metanlar

- $CHCl_3$:Kloroform, Trichloromethane (TCM)
- $CHCl_2Br$ bromodichloromethane Dicholorobromomethane (DCBM),
- $CHClBr_2$ (DCBM), Dibromochloromethane
- $CHBr_3$:Bromoform, Tribromomethane (TBM
- Toplam THMs

Ozonun yan ürünleri

EPA Groundwater Rule Update:
4-Log Removal Calculation Demonstration

Baffling Factor

EPA's proposed groundwater rule requires drinking water systems using groundwater to achieve 4-log removal/inactivation of viruses; i.e. 99.99% removal/inactivation. Removal/inactivation occurs through filtration and/or disinfection. Achieving this level of treatment may or may not be difficult depending on the unique conditions of the system; i.e. storage time, water temperature, peak flow and chlorine concentration. Inactivation is a function of the disinfectant concentration and the amount of time the water spends in contact with the disinfectant before the first service connection. The following spreadsheet provides the calculations needed to determine if your system can achieve 4-log removal. The example is a hypothetical groundwater system with a 6 inch main, no tank storage and 1,000 feet before the first service connection (storage volume based on the volume of 1,000 feet of 6 inch pipe). The example shows 4-log is achieved for the conditions indicated. Contact time is a function of the system's storage volume (in tanks and/or distribution system prior to the first service connection) and peak hourly flow. The spreadsheet (activate by double clicking within the table) can be used by entering a system's unique parameters; see instructions below. Chlorine, pH, temperature and peak flow are normal system measured values while storage volume has to be calculated if not already known. This will allow you to see what chlorine concentrations and storage times are needed for your particular system.

Example 4 log Calculation

Baffling Factor 1

1	2	3	4	5	6	7	8	9	10	11
Cl Conc	**pH**	**Temp**	**Peak Flow**	**Storage**	**Total Detention**	**Contact time**	**CT calc**	**CT req**	**Inactivation ratio**	**Log removal**
mg/L		°C	GPM	**Volume**	**Time (TDT)**	min	Cl Conc x	table B2	CT calc/CT req	4 X Inactivation Ratio
				Gallons	Vol/Peak Flow	TDT x Baffling Factor	Contact Time			
1.5	7	10	250	1468	5.87	5.87	8.81	6	1.47	5.87

Has to be 4 or above

Table 4-2
Baffling Factors

Factor	Description
0.1	None, agitated basin, very low length to width ratio, high inlet/outlet velocities
0.3	Single or mutliple unbaffled inlets or outlets, no intra-basin baffles
0.5	Baffled inlet/outlet with some intra-basin baffling
0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders
1	Very high length to width ratio (pipeline flow) perforated inlet, outlet and intra-basin baffles

TABLE B-2
CT VALUES* FOR
4- LOG INACTIVATION OF VIRUSES BY FREE CHLORINE

Temperature (°C)	pH 6-9	pH 10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

pH Ayarı Gerekmediği Halde Asit veya Baz Tankları Eklenmesi

Klor Emniyeti

Klor: Acil Durum Tedbirleri

Types of application:

- Chlorine dioxide: Cl_2O
- Sodium Hypochlorite: NaClO
- Calcium Hypochlorite: $Ca(ClO)_2$
- Gas Chlorine: Cl_2

Chlorine in Waste Water

General Aspects of Chlorine Application (I)

- Adding chemical agents:
  => contaminating purified effluent
  => undesired side-effects and by-products
- Residual as advantage in drinking water turns into disadvantage in waste water:
  => disinfectant as contaminant
- Environmental and safety concerns rise costs by
  => environmental impact studies
  => redundancy and safety equipment

Chlorine in Waste Water

General Aspects of Chlorine Application (II)

- Chlorine disinfection is also limited by suspended solids
  => tailoring effect on dose-response curve
- Resistance against chlorine reported
  => may require higher chlorine dosages
- Chlorine to be seen as global-warming-relevant substance
- Chlorinated substances partially to be seen as carcinogenic

Chlorine in Waste Water

Chlorine dioxide: Cl_2O

- Produced on-site by Cl_2 + NaClO or NaCl + HCl
  => high operational risk by strong acids/oxidants
- Very aggressive and resistant
  => oxidation of organic matter
  => strong persistence in effluent
- No formation of THM
- More common in drinking water

Chlorine in Waste Water

Calcium Hypochlorite: $Ca(ClO)_2$

- Preparation on site by dissolving tablets / powder
- Preparation can not completely be automated
- Solution is relatively unstable:
  => need for quick consumption
  => regular preparation required
- High pH
  => operational risk due to aggressiveness
- High cost of consumption of chemicals
  => mostly applied for small flow rate

Sodium Hypochlorite: NaClO

- Solution is relatively unstable:
  => need for quick consumption
  => regular supply required or:
  Production on site by electrolysis:
  => high impact on equipment
  => HCl for cleaning required
- High pH
  => operational risk due to aggressiveness
- High cost of consumption of chemicals
  => mostly applied for small flow rates

Gas Chlorine: Cl_2 (I)

- Most common chemical disinfectant in waste water
- Transported as liquid to site in cylinders or ton containers
- High risk of emission of gas chlorine
- Introduction into effluent is temperature – sensitive:
  => liquid chlorine highly aggressive
  => condensation has to be avoided
  => temperature to be controlled !

Chlorine in Waste Water

Gas Chlorine: Cl_2 (II)

- High demands require an Cl_2 evaporator
  => strong increase in operation and maintenance
- Cl_2 strongly absorbed by Ammonia and BOD:
  => increase of Cl_2 consumption
- Formation of Trihalomethan (THM) and AOX
  => depending on residence time, pH, Chlorine-concentration and TOC-concentration
- Discharge limits may require De-chlorination:
  Sulfur dioxide or sodium bisulphite are used for absorption of residual chlorine

Chlorine in Waste Water

Gas Chlorine: Cl_2 (III)

De-chlorination of gas-chlorine treated effluent heavily affects costs:

- Invest:
  increase by 70 % to 100% based on gas chlorination equipment; depending on flow rate
- Operation:
  Consumption of chemicals increases by 70% to 130% based on gas chlorine consumption

Chlorine in Waste Water

Investment Costs for Civils

- Chlorine always requires a tank for 20 – 30 min residence time.
  Example with 2500 m^3/hr :

Chlorine tank:	20 min	=>	840 m^3
UV channel:	TAK 9-5x2i1 HP	=>	20 m^3

  => UV: 98% less excavation; at lower depth !
- Chlorine equipment always requires a housing
- Storage facilities for gas chlorine or liquid agents including safety equipment required

Chlorine in Waste Water

Operational Costs

- Chlorine dosage (< 1.000 FC/100ml):
  raw or primary treated effluent: 10 – 25 mg/l
  secondary treated effluent: 4 - 10 mg/l
  tertiary (filtered) effluent: 1 - 5 mg/l

  => 2285 m^3/hr 2^{nd}ary effluent: 4 x 40 to trucks / a

- Hypochlorite: solution in litres of 10%:
  Chlorine: cylinders (75 kg) or containers (1 ton)

- Prices strongly depending on regional conditions
  => calculation to be made project-specifically

Chlorine in Waste Water

Chlorine in Waste Water