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KWWOA
Kentucky Water & Wastewater Operators Association

Math is Your Friend: Clarification Process Concepts and Math Calculations

April 11, 2018

Expected Learning Outcomes

- Attendees will be review math skills for wastewater operators to control a secondary treatment clarification process.
- Attendees will review applying arithmetic functions for process control performance insight in final clarification, RAS recycle and final effluent disinfection by chlorine.
- Gain insight into operating stress points for the disinfection process.
- Attendees will be provided more advanced process control concepts and calculations.

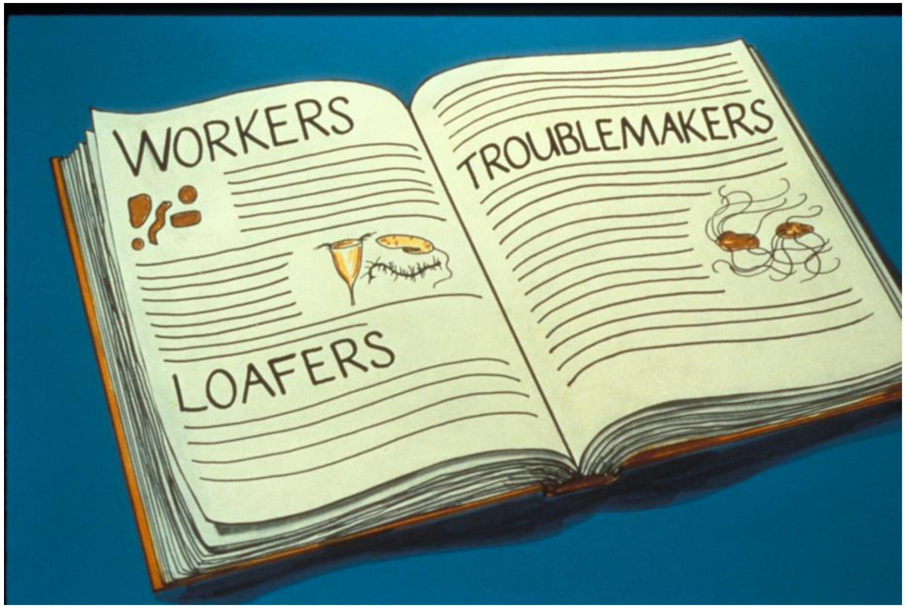
Agenda

Settling Process Calculations

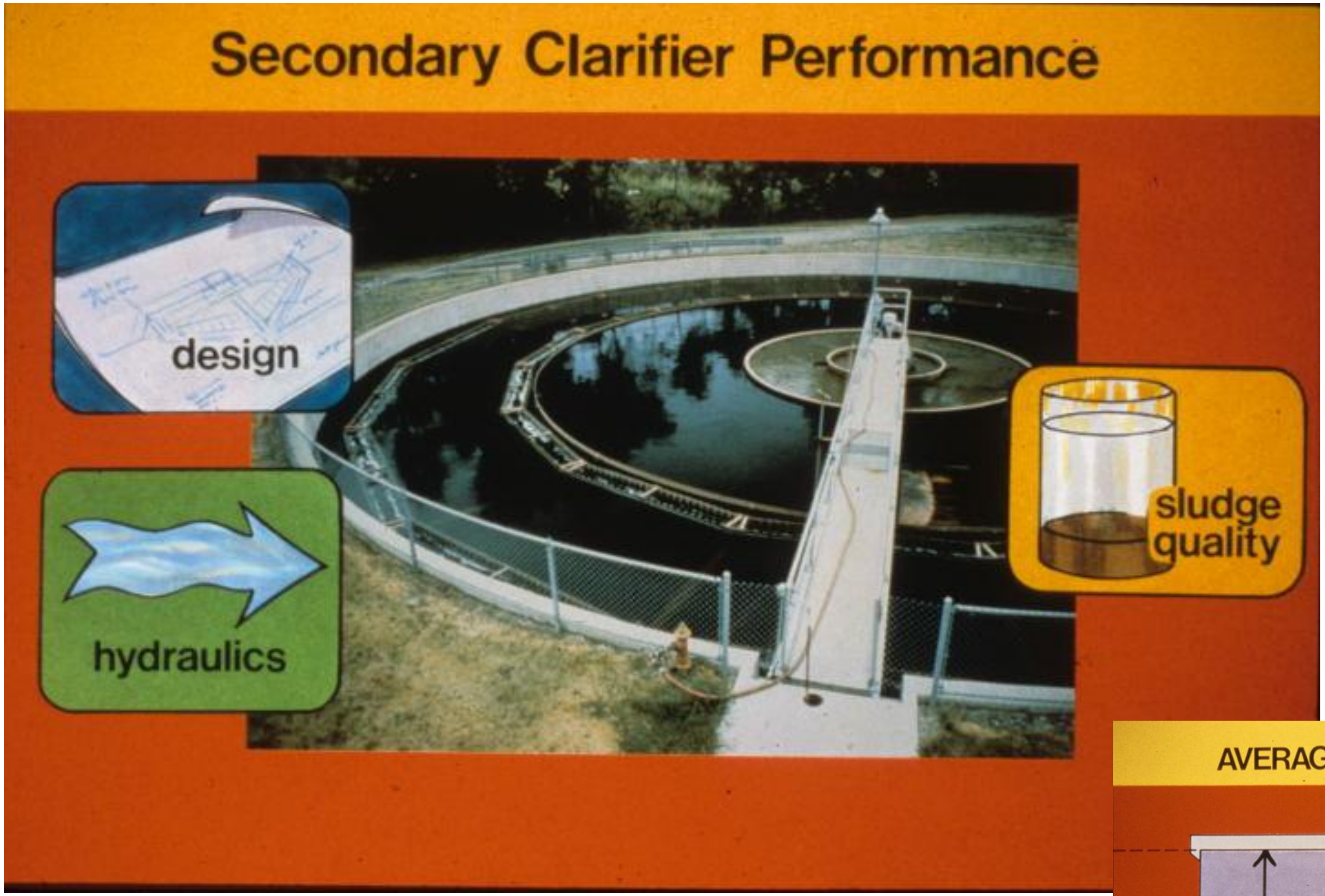
- Surface Overflow Rate
- Solids Loading Rate
- Settled Sludge Concentration
- Clarifier Sludge Flow Demand
- Sludge Blanket Movement
- Clarifier Sludge Detention Time
- RAS flow in Equilibrium

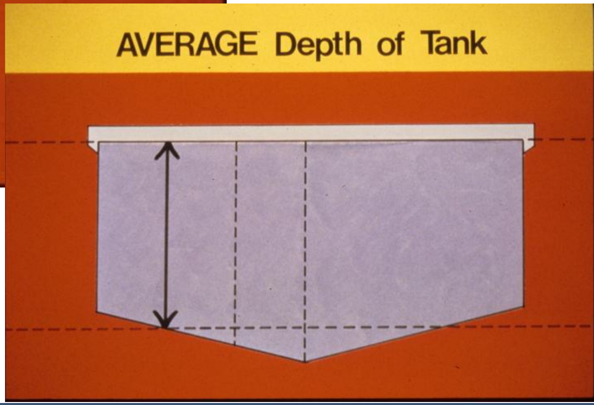
Final Disinfection

- CT Values



Secondary Settling Process Calculations





Surface Overflow Rate (SOR)

Flow rate in gallons per day per square foot of surface area

- The surface overflow rate (SOR) is expressed as gpd/sf. The SOR indicates the hydraulic momentum given to the floc particles entering the settling tanks. The momentum opposes the downward force of gravity pulling on the particle.
- Surface overflow rates were designed at 800 gpd/sf for average design conditions. Tighter limits have resulted in current practice lowering the SOR to 400 gpd/sf.
- Tank geometry, sidewater depth and current deflection baffles have all been employed to improve performance along with a conservative SOR of 400 gpd/sf for average design conditions and to improve performance at peak flow conditions.

Surface Overflow Rate (SOR)

Flow rate in gallons per day per square foot of surface area

SURFACE OVERFLOW RATE CALCULATION

Data Required:

a. Q_{INF}, Influent Flow Rate, 42,000,000 gpd
b. Total Surface Area of the Settling Tanks 1-6, 79,599 sf

Formula:

$$\text{SOR, gpd/sf} = \frac{Q_{INF}}{\text{Total Surface Area, sf}}$$

Solution:

$$\text{SOR, gpd/sf} = \frac{42{,}000{,}000 \text{ gpd}}{79{,}599 \text{ sf}}$$

$$= \mathbf{528 \text{ gpd/sf}}$$

Surface Overflow Rate (SOR)

Flow rate in gallons per day per square foot of surface area

SURFACE OVERFLOW RATE CALCULATION

Data Required:

a. Q_{INF}, Influent Flow Rate, 66,000,000 gpd
b. Total Surface Area of the Settling Tanks 1-6, 79,599 sf

Formula:

$$\text{SOR, gpd/sf} = \frac{Q_{INF}}{\text{Total Surface Area, sf}}$$

Solution:

$$\text{SOR, gpd/sf} = \frac{66{,}000{,}000 \text{ gpd}}{79{,}599 \text{ sf}}$$

$$= \mathbf{829\ gpd/sf}$$

Solids Loading Rate

Pounds of solids (mixed liquor) applied to each sf of surface area in the clarifier

- The Solids Loading Rate (SLR) is the second hydraulic calculation used to assure the plant is operating within normal loading ranges. The SLR accounts for
  - solids concentration in the mixed liquor and
  - the RAS flow rate in addition to the influent flow rate.
- While the SOR (surface overflow rate) may not be excessive, peak flows can push solids out of the aeration tank and overload the clarifiers ability to settle and concentrate solids.
- Current practice utilizes step feed / contact stabilization in aeration to reduce solids loading rates and increase the peak flow capacity of the clarifiers.

Solids Loading Rate

Pounds of solids (mixed liquor) applied to each sf of surface area in the clarifier

SOLIDS LOADING RATE CALCULATION

Data Required:

a. Q_{INF}, Influent Flow Rate, 33 MGD
b. Total Surface Area of the Settling Tanks, 79,599 sf
c. MLSS Concentration, 2,600 mg/L
d. RAS Flow Rate, 29.6 MGD

Formula:

$$\text{Solids Loading Rate, SOR lbs/d/sf} = \frac{(Q_{INF} + Q_{RAS}) \times \text{MLSS, mg/L} \times 8.34\ \text{lbs/gal}}{\text{Total Surface Area, sf}}$$

Solution:

$$\text{Solids Loading Rate, SOR lbs/d/sf} = \frac{(33 + 29.6) \times 2{,}600\ \text{mg/L} \times 8.34\ \text{lbs/gal}}{79{,}599\ \text{sf}}$$

$$= \mathbf{17.05\ lbs/day/sf}$$

Solids Loading Rate

Pounds of solids (mixed liquor) applied to each sf of surface area in the clarifier

SOLIDS LOADING RATE CALCULATION

Data Required:

a. Q_{INF}, Influent Flow Rate, 53 MGD
b. Total Surface Area of the Settling Tanks, 79,599 sf
c. MLSS Concentration, 2,600 mg/L
d. RAS Flow Rate, 47.5 MGD

Formula:

$$\text{Solids Loading Rate, SOR lbs/d/sf} = \frac{(Q_{INF} + Q_{RAS}) \times \text{MLSS, mg/L} \times 8.34\ \text{lbs/gal}}{\text{Total Surface Area, sf}}$$

Solution:

$$\text{Solids Loading Rate, SOR lbs/d/sf} = \frac{(53 + 47.5) \times 2{,}600\text{, mg/L} \times 8.34\ \text{lbs/gal}}{79{,}599\ \text{sf}}$$

$$= \mathbf{27.4\ lbs/day/sf}$$

Settled Sludge Concentration

Compare Laboratory Settling Compaction to RAS concentration

The settling test provides an important sludge quality calculation which provides insight into sludge compaction and expected RAS concentrations. As sludge settles, it becomes more concentrated.

SETTLED SLUDGE CONCENTRATION

Data Required:

a. MLSS, Mixed Liquor concentration, 2,600 mg/L
b. SSV, Settled Sludge Volume Reading, 250 cc/L

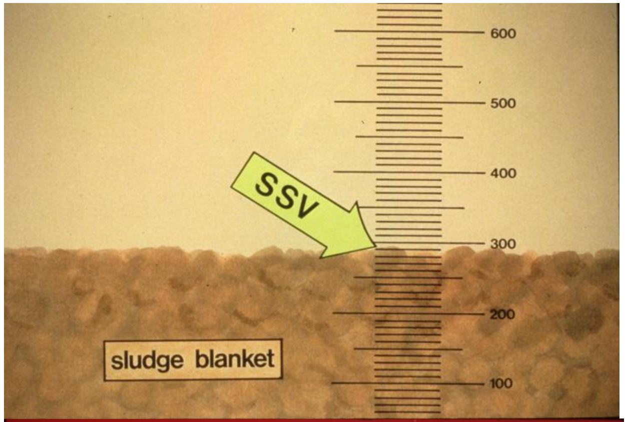
Formula:

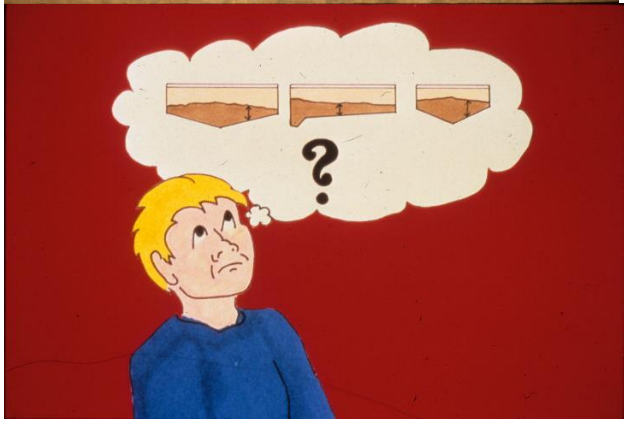
$$\text{SSC, mg/L} = \frac{(\text{MLSS, mg/L}) \times (1{,}000)}{\text{SSV}}$$

Solution:

$$\text{SSC, mg/L} = \frac{(2{,}600) \times (1{,}000)}{250}$$

$$= \mathbf{10{,}400\ mg/L}$$





Clarifier Sludge Flow Demand

Optimized RAS flow rate to match Settled Sludge Concentration

- Return sludge control using the SSC method can generate a Clarifier Sludge Flow Demand (CSFD) value.
- The CSFD value is the theoretical flow rate that would be optimum for the selected SSC concentration value.
- This calculation points you in a direction for adjusting the RAS flow rate.
- Typically the SSC value between the 30 and 60 minute settling time is used for estimating adjustment purposes.

Clarifier Sludge Flow Demand

Optimized RAS flow rate to match Settled Sludge Concentration

CLARIFIER SLUDGE FLOW DEMAND CALCULATION

Data Required:

a. Current return sludge flow, RSF, 29.6 MGD.
b. Current return sludge concentration, RSC, 5,500 mg/L
c. Current mixed liquor concentration, ML, 2,600 mg/L
d. Selected settled sludge concentration, SSC, 10,400 mg/L

Formula:

$$\text{CSFD, MGD} = \frac{(\text{RSF, MGD}) \times (\text{RSC, mg/L} - \text{MLSS, mg/L})}{(\text{SSC, mg/L} - \text{MLSS, mg/L})}$$

Solution:

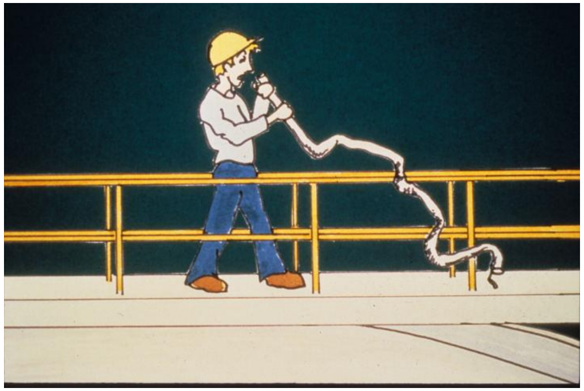
$$\text{CSFD, MGD} = \frac{(29.6\ \text{MGD}) \times (5{,}500 - 2{,}600)}{(10{,}400 - 2{,}600)}$$

$$= \mathbf{11\ .01\ MGD}$$

Sludge Blanket Movement

Compare lbs/hr solids in settling versus lbs/hr solids out (RAS)

SLUDGE BLANKET MOVEMENT



Data Required:

a. Return sludge flow, RAS Flow, 29.6 MGD
b. Return sludge concentration, RAS, 5,600 mg/L
c. Mixed Liquor Concentration, MLSS, 2,600 mg/L
d. Influent Flow Rate, 43 MGD

Formula:

$$CSF\ (lbs/hr) = \frac{(Inf.\ MGD + RAS,\ MGD) \times (MLSS,\ mg/L) \times 8.34\ lbs/gal\ /\ 24\ hours/day}{(RAS,\ MGD) \times (RAS,\ mg/L) \times 8.34\ lbs/gal\ /\ 24\ hours/day}$$

Solution:

$$CSF\ (lbs/hr) = \frac{(43 + 29.6\ MGD) \times (2{,}600) \times 8.34 / 24}{(29.6) \times (5{,}600) \times 8.34 / 24}$$

= 65,594 lbs MLSS IN
57,602 lbs RAS OUT

Clarifier Sludge Detention Time

Blanket pounds compared to RAS pounds being removed

CLARIFIER SLUDGE DETENTION TIME CALCULATION

Data Required:

a. RAS flow rate, Q_{RAS}, 4.9 MGD (Clarifier 3)
b. Mixed Liquor Suspended Solids, MLSS = 2,500 mg/L
c. RAS, 5,500 mg/L
d. Blanket depth, Clarifier 3; DOB = 4.5 feet
e. Clarifier 3 volume per foot, V = 0.0992 MG

Formula:

$$\text{Sludge Detention Time, hrs.} = \frac{(DOB \times V \times (MLSS, mg/L + RAS, mg/L)/2) \times 24}{(RAS, MGD \times RAS, mg/L)}$$

Solution:

$$\text{Sludge Detention Time, hrs.} = \frac{(4.5 \times 0.0992 \times (2{,}500 + 5{,}500) / 2) \times 24}{(4.9 * 5{,}500)}$$

$$= \textbf{1.59 hours}$$

RAS Flow in Solids Equilibrium

No Blanket Movement – Assume no Increase or Decrease in DOB

RAS FLOW IN SOLIDS EQUILIBRIUM CALCULATION

Data Required:

a. Current Influent Flow, Q_{INF}, 33 MGD.
b. Current RAS (return sludge) concentration, RASss, 5,500 mg/L.
c. Current mixed liquor concentration, MLSSss, 2,600 mg/L

Formula:

$$\text{RAS, MGD} = \frac{(Q_{INF}\ \text{MGD}) \times (\text{MLSSss, mg/L})}{(\text{RASss, mg/L - MLSSss,mg/L})}$$

Solution:

$$\text{RAS, MGD} = \frac{(33\ \text{MGD}) \times (2{,}600\ \text{mg/L})}{(5{,}500\ \text{mg/L} - 2{,}600\ \text{mg/L})}$$

$$\frac{(85{,}800\ \text{MGD mg/L})}{(2{,}900\ \text{mg/L})}$$

$$= \mathbf{29.6\ MGD}$$

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RAS Flow in Solids Equilibrium

No Blanket Movement – Assume no Increase or Decrease in DOB

RAS FLOW IN SOLIDS EQUILIBRIUM CALCULATION

Data Required:

a. Current Influent Flow, Q_{INF}, 33 MGD.
b. Current RAS (return sludge) concentration, RASss, 7,000 mg/L.
c. Current mixed liquor concentration, MLSSss, 2,600 mg/L

Formula:

$$\text{RAS, MGD} = \frac{(Q_{INF}\ \text{MGD}) \times (\text{MLSSss, mg/L})}{(\text{RASss, mg/L} - \text{MLSSss,mg/L})}$$

Solution:

$$\text{RAS, MGD} = \frac{(33\ \text{MGD}) \times (2{,}600\ \text{mg/L})}{(7{,}000\ \text{mg/L} - 2{,}600\ \text{mg/L})}$$

$$\frac{(85{,}800\ \text{MGD mg/L})}{(4{,}400\ \text{mg/L})}$$

= 19.5 MGD

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Disinfection

Math is Your Friend: Disinfection Process Concepts and Math Calculation

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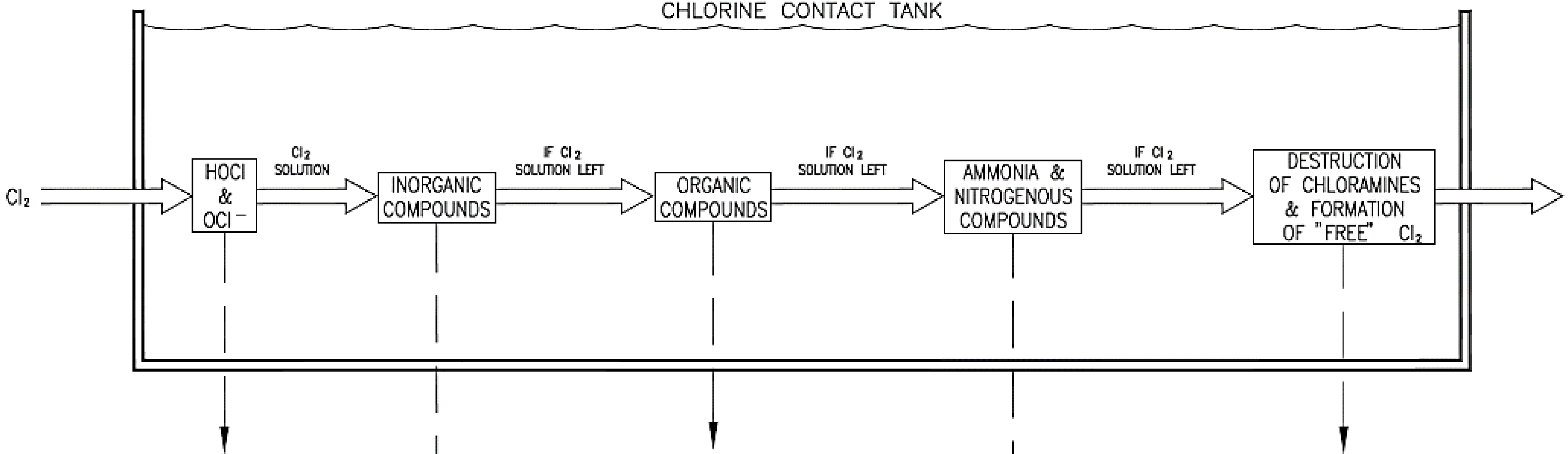
How Effective is the Chlorine for Disinfection?

- Sufficient chlorine must be added to ensure chlorine demand can be met while maintaining a Total Residual.
- Chorine demand – Inorganic compounds react quickly and use the chlorine. There is not disinfection capability from the inorganic compounds that react with chlorine.
- Nitrite is present due to incomplete nitrification and each part of nitrite uses 5 parts of chlorine.
- Organics also use up chlorine and provide little disinfection power.
- Total suspended solids is significant because it helps to impart demand but also shields embedded bacteria and fecal coliform.

BASIC CHLORINATION REACTIONS



A combination of HOCl & OCl^- is formed in milliseconds upon addition of Cl_2 to water. The predomination of HOCl or OCl^- is pH dependant. This combination is termed "free chlorine" and exists initially for only seconds.

The chlorine solution first reacts with inorganic compounds including reducing agents. These compounds may occur naturally in wastewater or may originate from industrial wastes. Examples include hydrogen sulfide, ferrous iron, manganese, sulfur dioxide and nitrite. The combination of chlorine and inorganic compounds have no disinfecting value.

The combination of organic compounds and chlorine solution is referred to as "chlororganics". This combination has little or no disinfecting value.

Chlorine solution and ammonia form chloramines (monochloramines, dichloramines & trichloramines). Chloramines, especially mono-chloramines have disinfecting values.

If enough Cl_2 is added to accomplish this stage, this stage is referred to as "breakpoint chlorination". Free chlorination possess the greatest disinfecting values but, Cl_2 is rarely applied to this degree in wastewater.

How Effective is the Chlorine for Disinfection?

- The disinfecting power of chlorine is affected primarily by:
  - Residual concentration
  - Time
- Disinfecting Power of Chlorine is also impacted by temperature. Minimum temperature is monitored because the chlorine's ability to disinfect is reduced with temperature.
- Disinfecting Power of chlorine is also reduced as the pH increases.
  - When chlorine is dispersed in water, hypochlorous acid (HOCL) and hypochlorite (OCL^-) form until they quickly react with the chlorine demand. If the water is acidic, the free H+ ions will keep the HOCL in solution longer. HOCL is 20x the germicide as OCL^-

How Effective is the Chlorine for Disinfection?

- The Disinfection power of chlorine is commonly expressed as a CT Value. (CT stands for Concentration X Time). Used on the drinking water side of business.
- Concentration is in ppm/mg/L while time is in minutes. Minimum chlorine residual should be used to calculate the CT Value to ensure the Fecal Coliform is deactivated.
- As the contact time is reduced during high flows, chlorine residual must be increased to compensate for the loss of time.
- CT Values:
  - 32 MGD: 24 minutes @ 1.5 mg/L: CT Value = 48
  - 42 MGD: 19 minutes @ 2.2 mg/L: CT Value = 48
  - 84 MGD: 10 minutes @ 4.8 mg/L: CT Value = 48
- The CT value remains consistent with a decrease in contact time and an increase in residual chlorine.

Questions

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