Maximizing Disinfection Reactor Ct via Integration of Chlorine Demand and Decay

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PNWS AWWA Conference | Spokane, Washington

May 7-10, 2013

Brown AND Caldwell

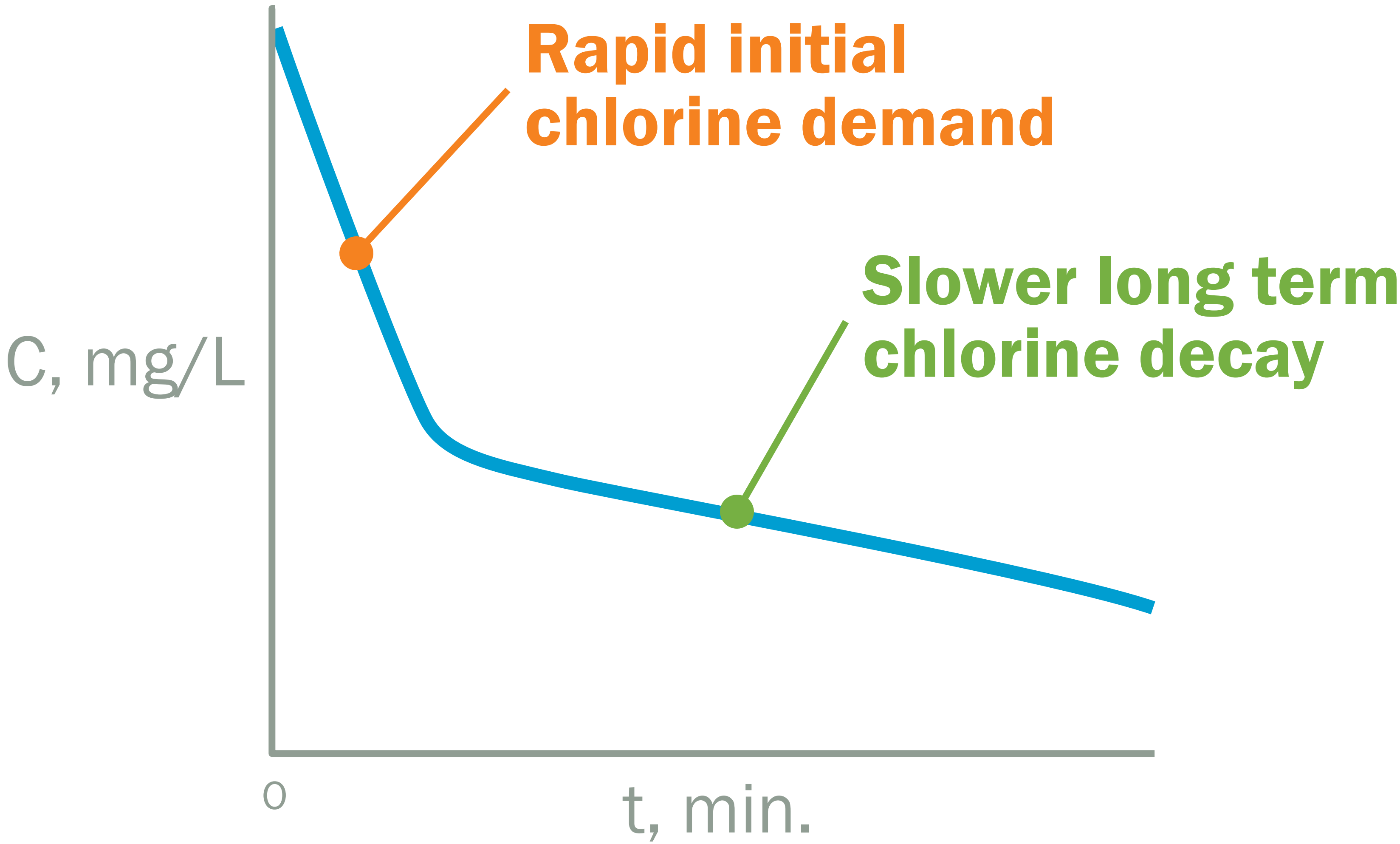
Presentation Summary
Free Chlorine Ct Computations

- Present Reactor Ct Computations
- Suggested Integration Method for Ct
- Two-stage Algorithm for Predicting CDD
- Integration of CDD Algorithm
- Application of CDD Algorithm Integration

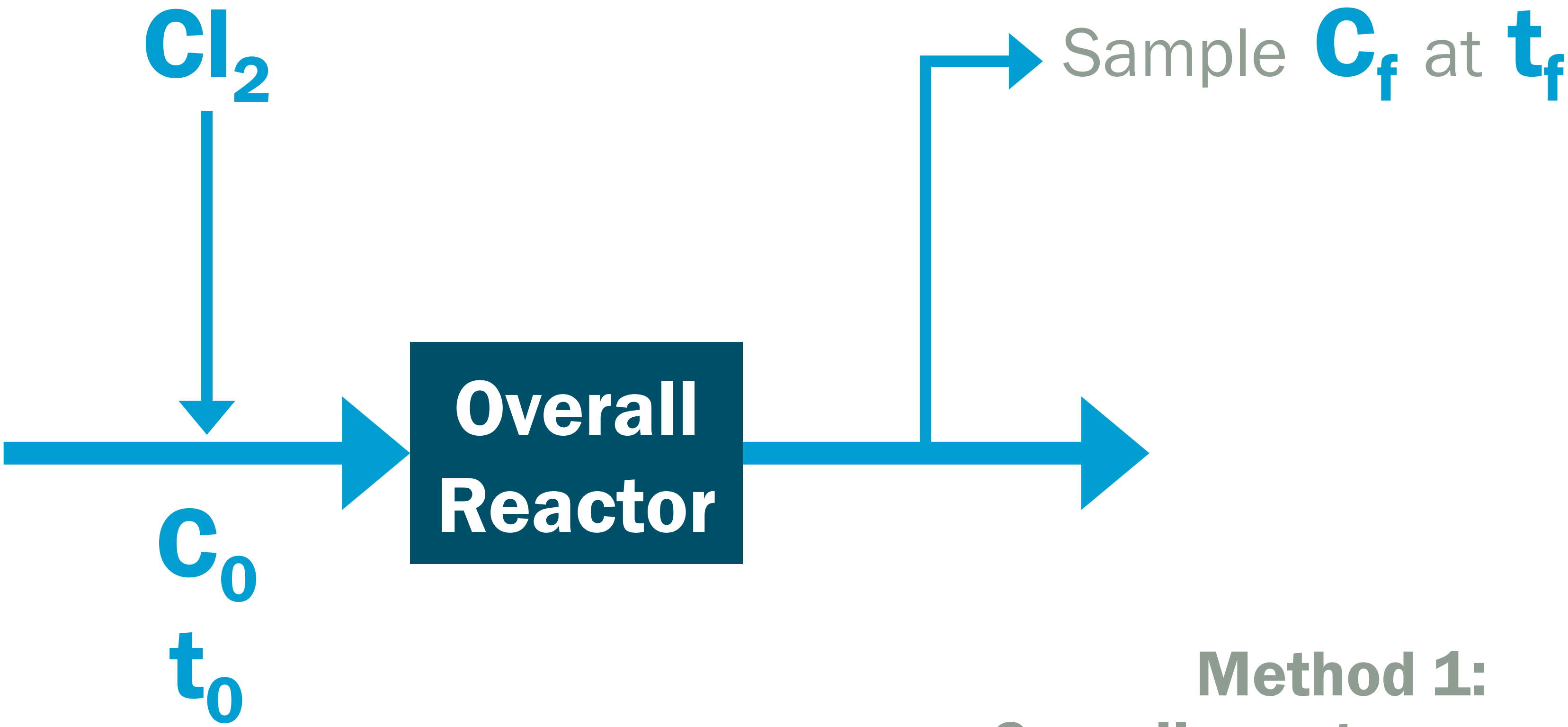
Importance of Ct Computations

- Protect Water Quality
  - Pathogen inactivation
  - DBP Minimization
- Assure compliance with disinfection regulations
- Meet regular reporting requirements

Typical CDD Profile

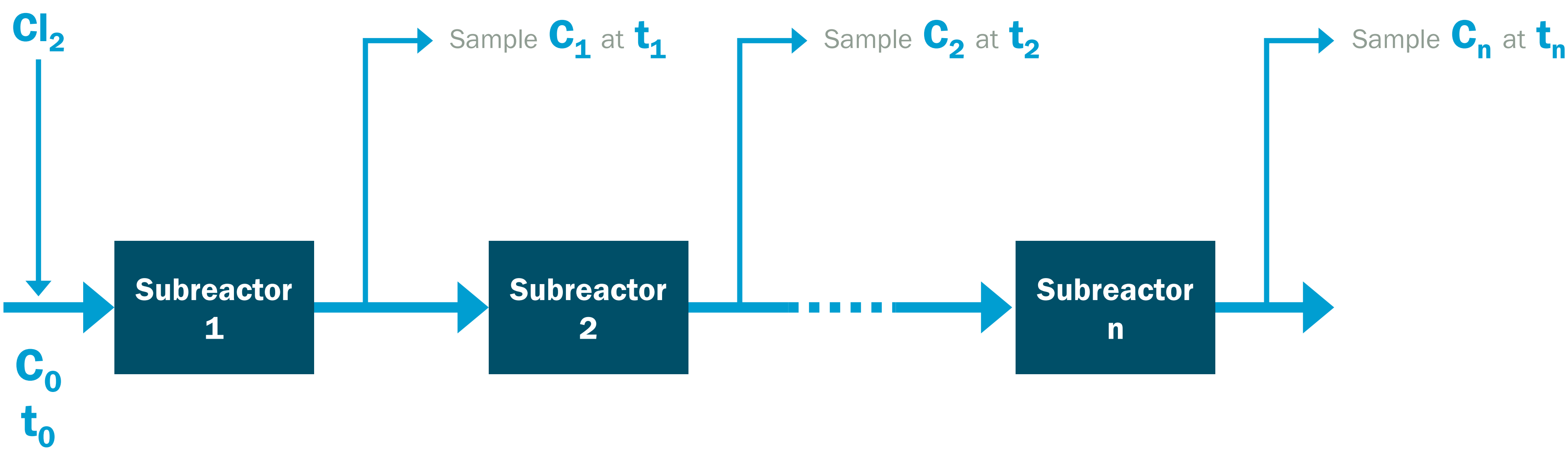


Two Existing Simple Methods to Compute Ct



Method 1:
Overall reactor sampling
$Ct = C_f \times t_f$

Two Existing Simple Methods to Compute Ct



Method 2:
Intermediate reactor sampling

$$Ct = \sum_{j=1}^{j=n} C_j (t_j - t_{j-1})$$

Existing methods

- Only accounts for reactor discharge concentration
- Ignores added value of CDD within reactor

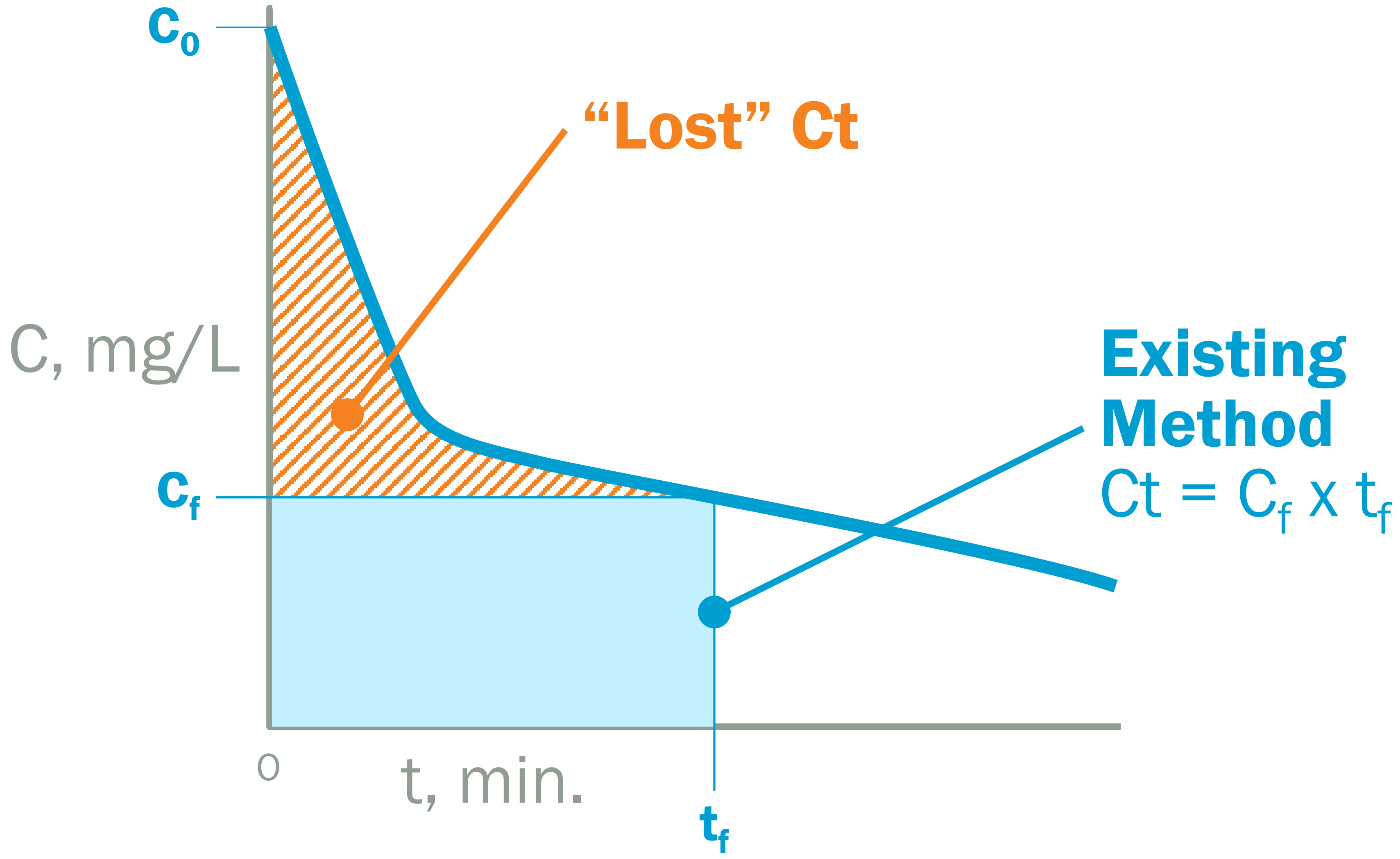
Is there a better way?

Yes!

New Method

- Mathematical model for CDD
- Integrate model
- Account for “lost” Ct value
- Helps when available Ct is “tight” or water is reactive

Existing Method vs. New



CDD Algorithms

General form to predict C versus t

$$C = f\left(\begin{array}{l}\text{time, temp, DOC, pH,}\\ \text{oxidizable substances, others}\end{array}\right)$$

CDD Algorithms

The most basic, simplified form

Where **k** is a rate constant

$$C = C_0 e^{-kt}$$

CDD Algorithms

A more elaborate and accurate form

A
proportionality constant between rapid demand and slow decay

k
rate coefficient for rapid initial demand

l
rate coefficient for slower long term decay

$$C = C_0 A e^{-kt} + C_0(1-A)e^{-lt}$$

For short term applications,
can set A = 1 and ignore 2nd term

eq. 1 (Haas & Karra 1984)

Yet Another Algorithm Twist

Rate constants vary with temperature!

Higher temperatures increase CDD

- Use Arrhenius Law and van't Hoff equation

  $d(\ln k)/dT = \Delta H^0/(R_g T^2)$

ΔH^0 = 15,048 cal/gm-mole; R_g = 1.987 cal/^{0}K-gm-mole

Std. State Enthalpy Change

$$\mathbf{k} = k_s \mathrm{EXP}[\Delta H^0/(R_g T_s)]\mathrm{EXP}[-\Delta H^0/(R_g T)] \quad \text{eq. 2}$$

$$C = C_0 A e^{-kt} + C_0(1-A)e^{-lt}$$

$$\mathbf{l} = l_s \mathrm{EXP}[\Delta H^0/(R_g T_s)]\mathrm{EXP}[-\Delta H^0/(R_g T)] \quad \text{eq. 3}$$

Scare you?

It’s not so bad!

Combine equations 1, 2, and 3. It's simple to integrate, right?

Not so fast!

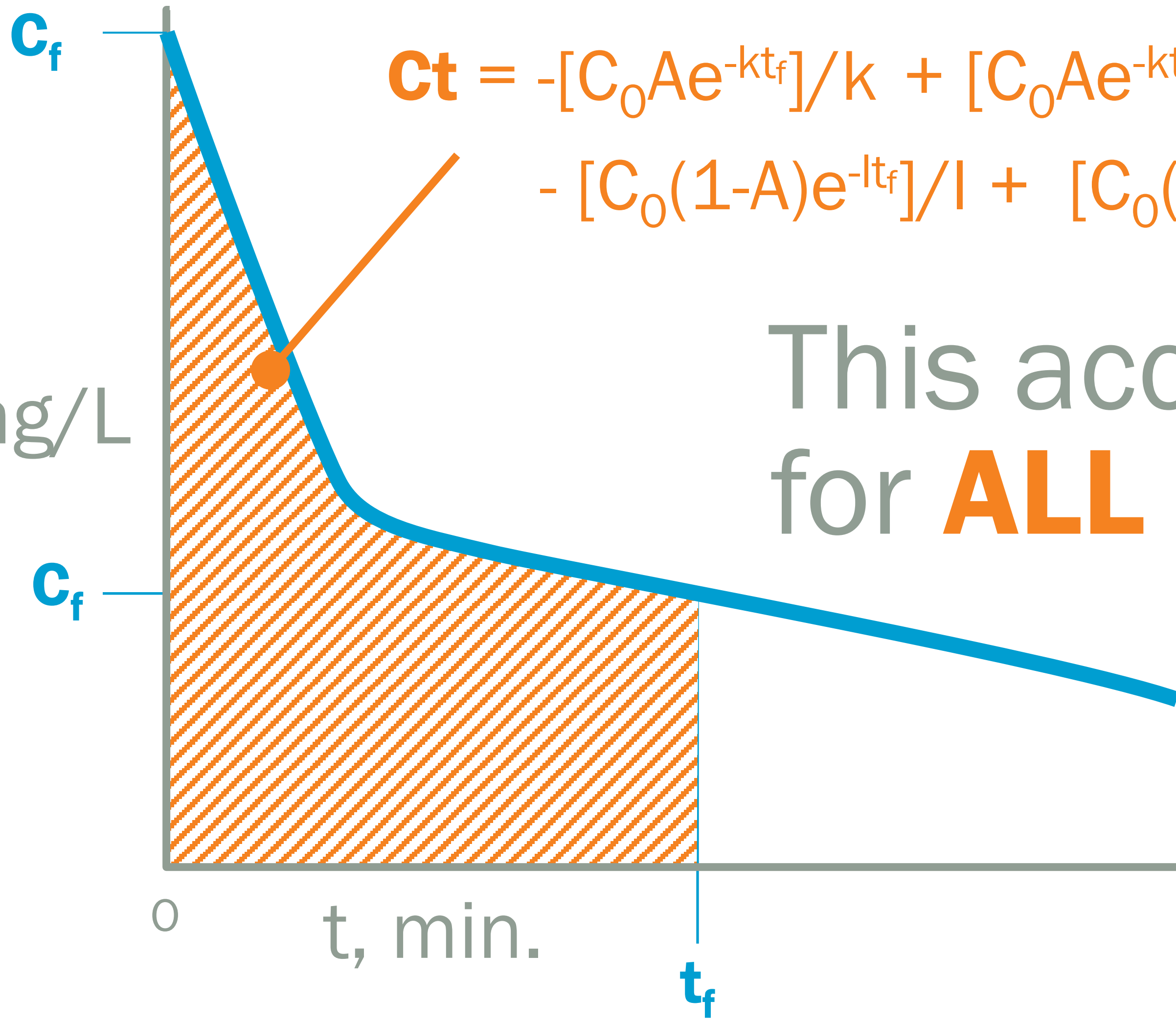
CDD Integration for Constant Temperature

$$Ct = \int C dt$$

$$Ct = \int_{t = t_0}^{t = t_f} C_0[Ae^{-kt} + (1-A)e^{-lt}]dt$$

- Analytical integration works at constant temperature
- Not true for varying temperature

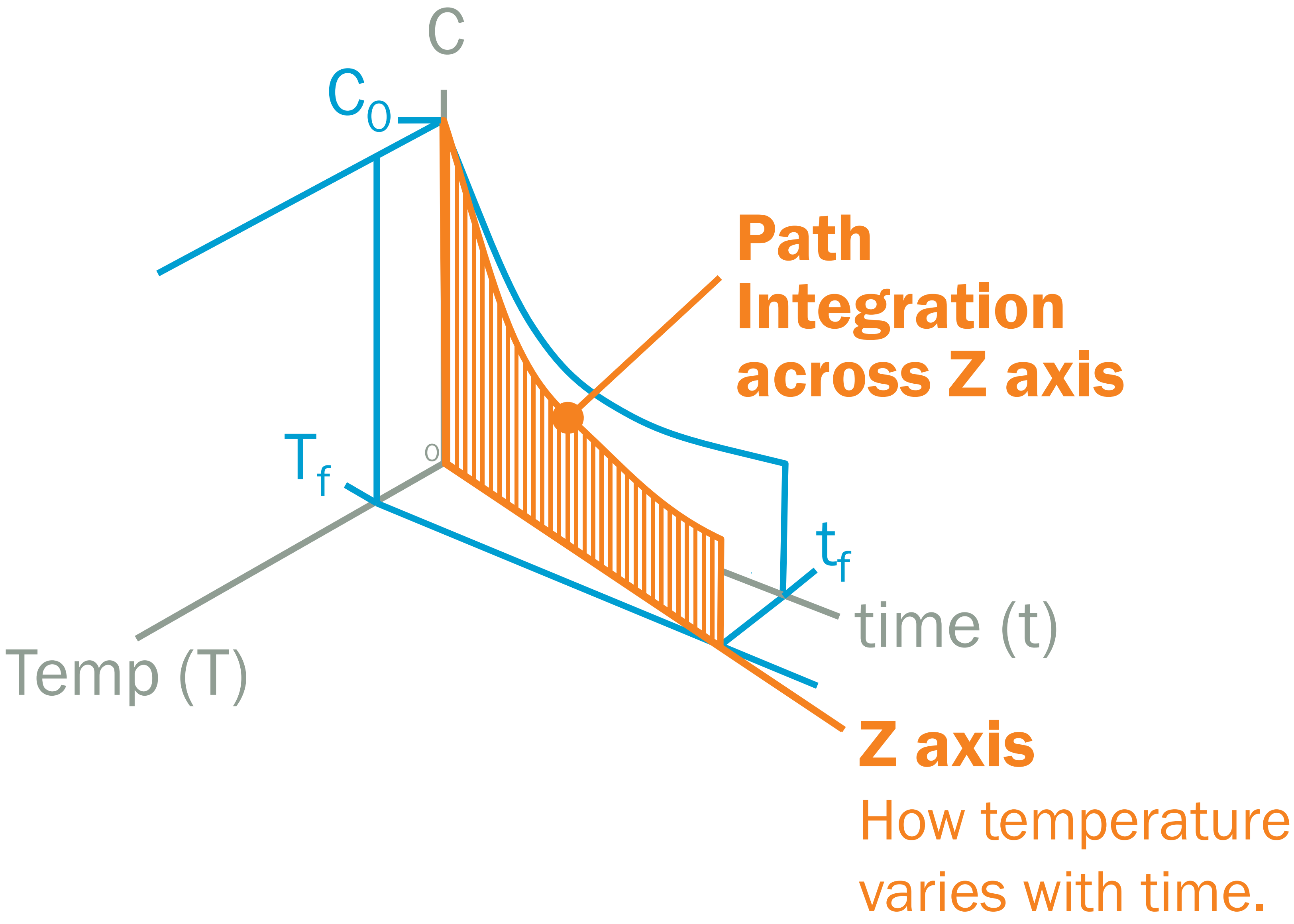
CDD Integration for Constant Temperature



$$Ct = -[C_0 A e^{-kt_f}]/k + [C_0 A e^{-kt_0}]/k - [C_0(1-A)e^{-lt_f}]/l + [C_0(1-A)e^{-lt_0}]/l$$

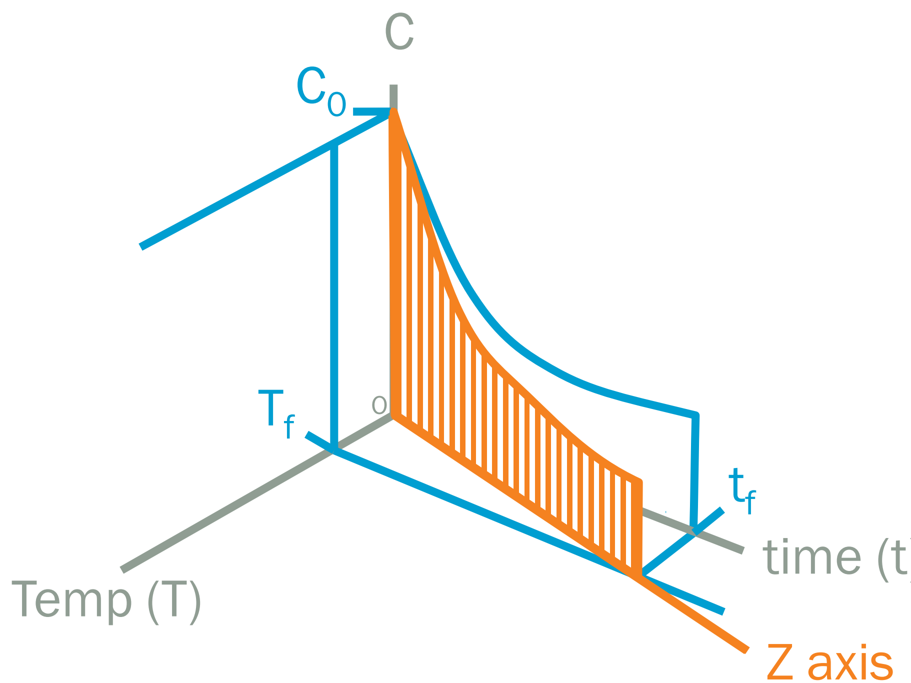
This accounts for **ALL** the Ct

CDD Varies with Time and Temperature



Integration for Varying Temperature

- For simplicity, assume T = linear f(t)
- Re-express T and t in equations 1, 2, and 3 in terms of Z
- *Cannot integrate analytically*
- Resort to numerical integration
  - Use Simpson's Rule
  - Slice curve into numerous parabolic segments
  - Add up segment areas under the curve



Now what?

Next Steps

- Perform lab test to measure CDD constants
- Apply math
  - There's a free App for that!
- When to apply this method?
- Will regulators accept this method?

Example Computations
NW City "X" WTP

Existing Method

GIVEN:

- 1.0 log inactivation credit via disinfection (direct filtration)
- Clearwell Volume: 325,000 gallons
- $t_{10}/t = 0.51$
- Flow = 8.4 mgd (5,833 gpm)
- pH = 7.8
- Temperature T_0 = 19°C (292°K)
- Temperature T_f = 20°C (293°K)
- C_f = 0.8 mg/L as Cl_2

Integration Method

GIVEN:

- Same clearwell conditions
- A = 0.314
- k_s = 0.0163 min^{-1}
- l_s = 0.00017 min^{-1}
- T_s = 292°K = 19°C

Empirical values determined from City "X" CDD Study

Example Computations
NW City "X" WTP

Existing Method

- t_f = (325,000)(0.51)/5,833 = 28.4 minutes
- Ct (available) = C_f x t_f = (0.8)(28.4) = 22.7 mg-min/L
- Ct (required) = 24.4 mg-min/L from Ct tables for 1.0 log inactivation
- **Log inactivation achieved = 22.7/24.4 = 0.9**
- Just barely miss the inactivation target
- Causes City "X" to prechlorinate for added Ct
- This practice aggravates DBPs

Integration Method

- t_f = (325,000)(0.51)/5,833 = 28.4 minutes
- Ct (available) = 24.4 mg-min/L
- Ct (required) = 24.4 mg-min/L from Ct tables for 1.0 log inactivation
- **Log inactivation achieved = 24.4/24.4= 1.00**
- Improvement in log inactivation over traditional method > 7%
- Improvement may be small, but important in some circumstances
- In this case…
  no need to prechlorinate!

Summary

- Account for **ALL** reactor Ct, not just discharge value
- Determine CDD reaction variables
- Integrate CDD operating equations
- More useful for reactive waters
- Optimize disinfection reactor performance
  - Use less chlorine
  - Reduce disinfection byproducts

Spend same time on the math…

with better results!

Questions?

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