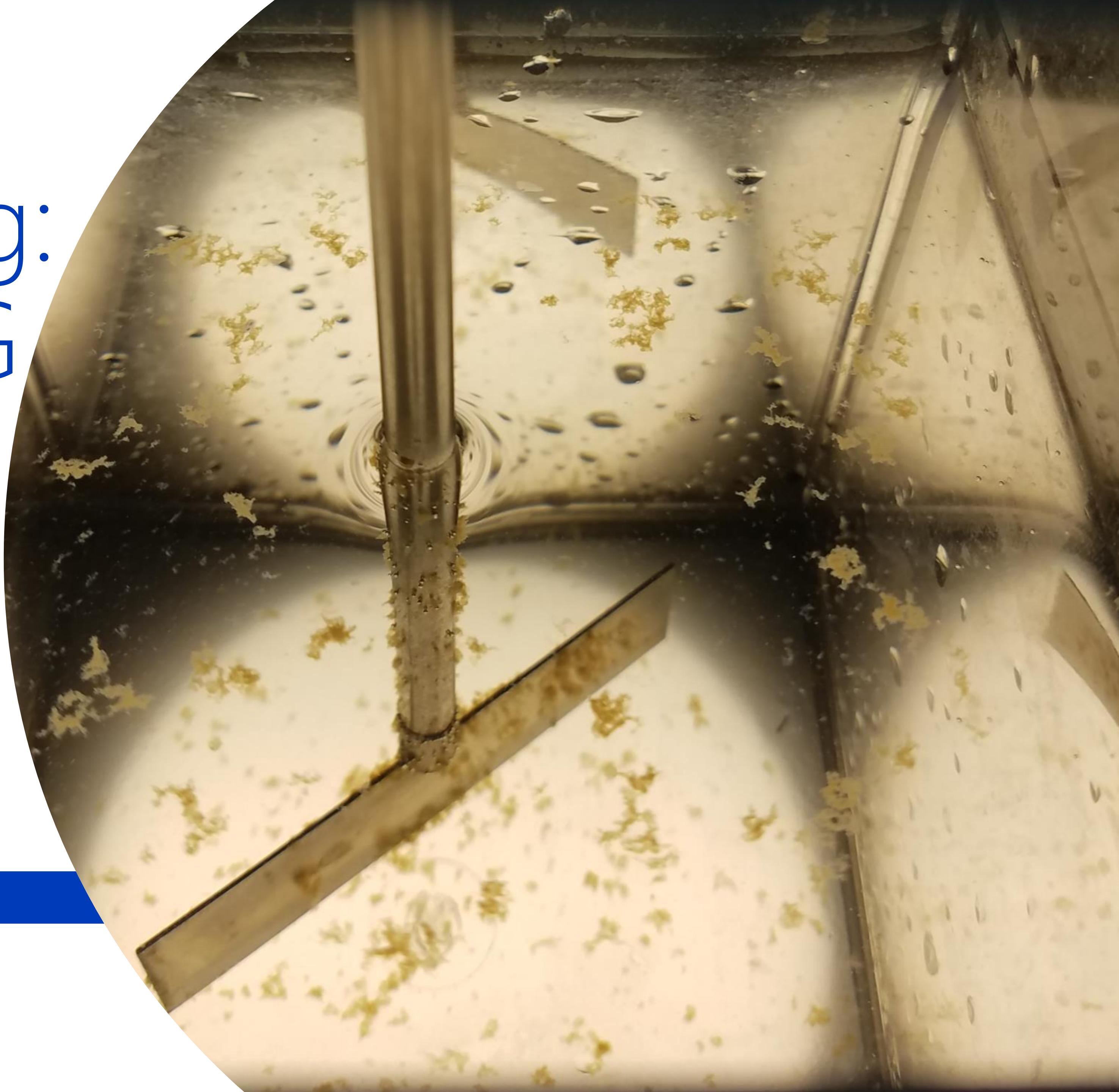
Chemical Mixing: Nothing But a G Thing?

2024 PNWS AWWA

Annual Conference

May 2, 2024



Agenda

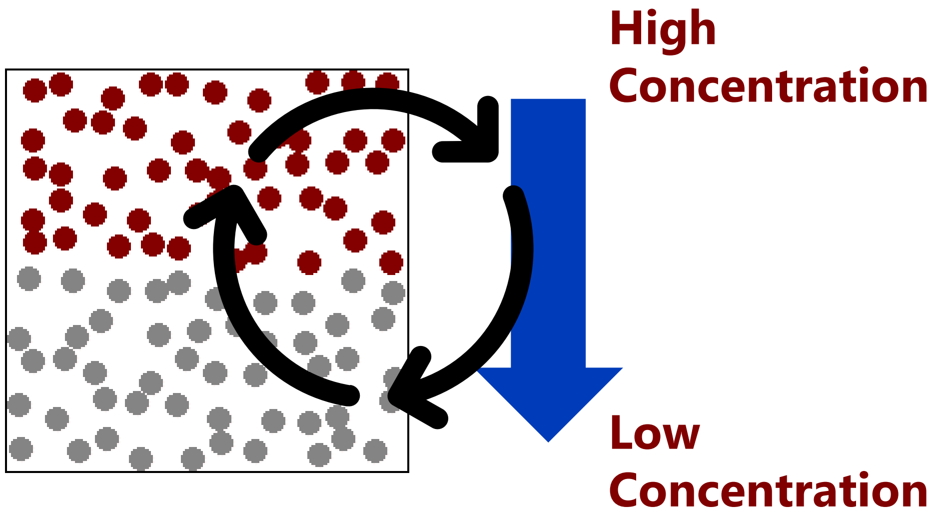
- What is G?
- Flash Mixing Technologies and G
- Flocculation Technologies and G
- Review of G Values and Design Criteria for Operating Plants
- Conclusion

01

What is G?

Chemical Mixing Theory

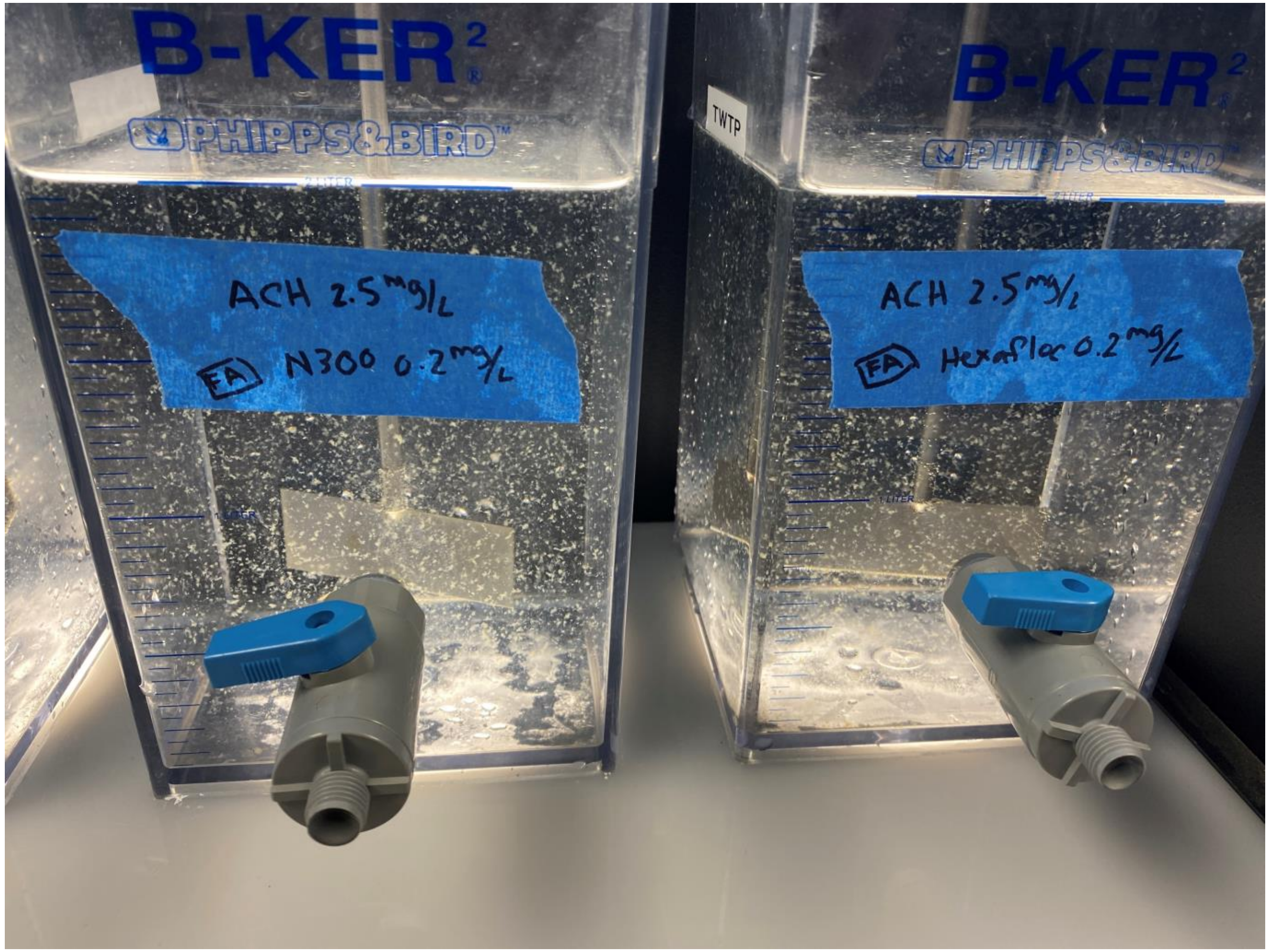
- In the absence of turbulence or external mixing energy input, molecular diffusion governs .
  - » Spreading out from random molecular movement.
- Water treatment commonly occurs in turbulent flow conditions.
  - » Turbulence creates eddies.
    - – Eddies transfer kinetic energy.
  - » Turbulent and molecular diffusion occur.



Agitation

- Induce motion in fluid to:
  - » Maintain particles in suspension.
  - » Promote particle contact.
    - – **Flocculation.**
  - » Mass transfer.
    - – **Aeration.**
    - – **Air stripping.**

Blending



- Combining two flow streams to achieve uniform mixing.
- WTP processes:
  - Chlorination.
  - pH control.
  - Fluoridation.
  - Rapid mixing (coagulation).

How to Define and Characterize Mixing?

- Velocity gradient (G), is commonly used in design of water treatment processes.
- G is derived from relationship between forces acting on fluid, velocity of fluid, and viscosity (resistance to movement).
- Ratio of power dissipated per unit volume.
- Averaged over entire mixing vessel volume (velocity gradient varies over time and space).

$$G = \sqrt{\frac{P}{\mu V}}$$

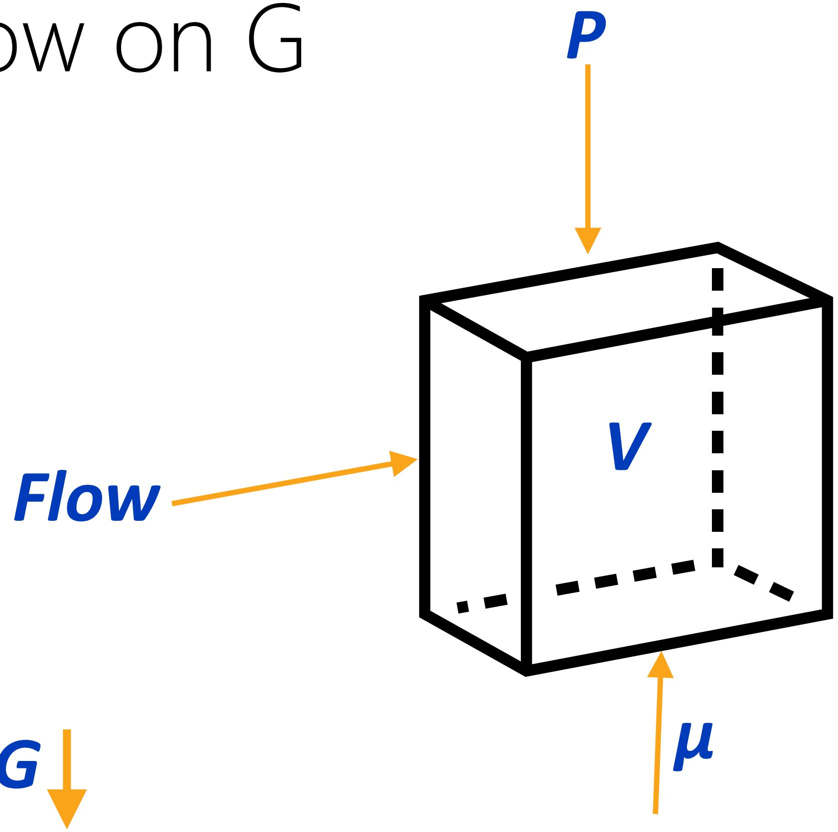
G = velocity gradient (s^{-1})
P = Power of mixing input (kW / HP)
V = Volume of mixing vessel (ft^3, m^3)
μ = Viscosity (N-s/m^2, lb-s/ft^2)

$$Gt$$

G = velocity gradient (s^{-1})
t = Mixing time (s)

Impact of Flow on G

$$G = \sqrt{\frac{P}{\mu V}}$$



$P\uparrow \longrightarrow G\uparrow$

$\mu\uparrow$ *(Temperature* $\downarrow$*)* $\longrightarrow G\downarrow$

$$Gt$$

Flow $\uparrow \longrightarrow$ G *(unchanged)*

Flow $\uparrow \longrightarrow t\downarrow Gt\downarrow$

G = velocity gradient (s^{-1})
P = Power of mixing input (kW / HP)
V = Volume of mixing vessel (ft^3, m^3)
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G = velocity gradient (s^{-1})
t = Mixing time (s)

02

Flash Mixing Technologies and G

Flash Mixing Technologies

- Purpose: Rapidly mix and blend chemical.
  - Critical for coagulation.
  - Coagulation reactions occur within seconds.
  - Rapid even mixing of chemical required to maximize neutralization of particles in water.

- Hydraulic Mixing
- Static Mixer

Potential energy in the water

- In-Line Mechanical Mixer
- Mechanical Flash Mixer (In-Tank)
- Pumped Jet Diffusion

External mechanical energy input

Hydraulic Mixing

- Turbulence created from induced head loss, cascading water, or hydraulic jump.
  - » Parshall flumes
  - » Weirs
  - » Orifice and Venturi meters
- *Mixing energy dependent on plant flow rate.*

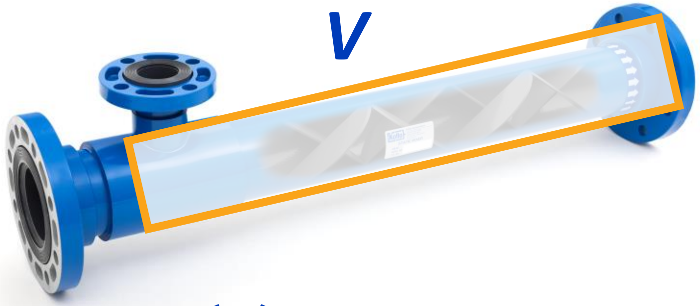
$$G = \sqrt{\frac{P}{\mu V}}$$

$$Gt$$

No common design criteria for flash mixing.

Static Mixer

- Induce head loss through torturous, turbulent flow path.
- *Mixing energy input is a function of plant flow rate.*
- Proprietary designs.
- Design Criteria:
  - » Gt = 350 – 1,700
  - » t = 1 – 5 seconds



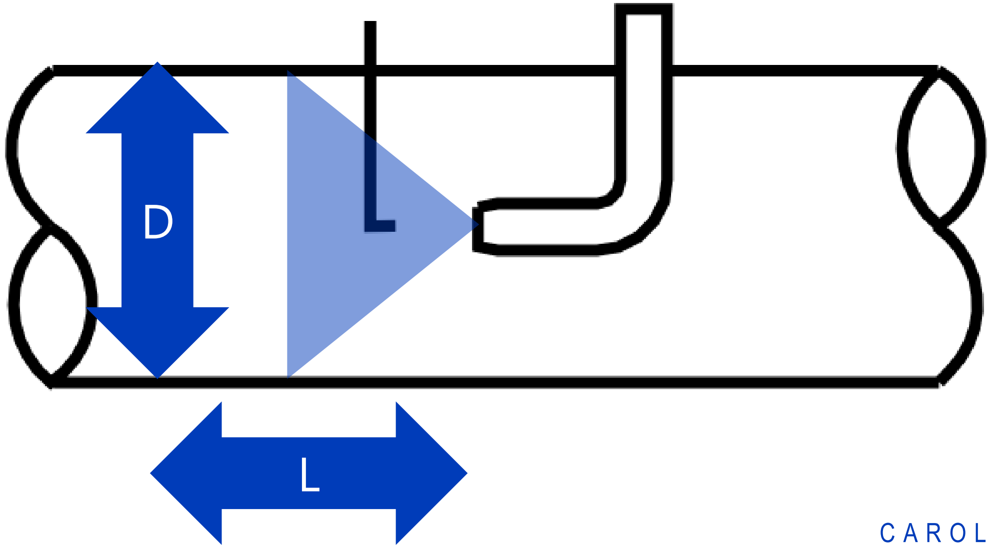
$$P = f(Q) = Head\ Loss$$

$$G = \sqrt{\frac{P}{\mu V}} \qquad Gt$$

Image Source: Koflo Corporation

Pumped Diffusion

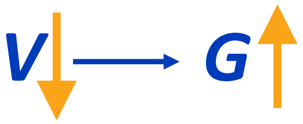
- Pressurized water jet mixes with injected chemical.
- Minimal head loss, no moving components inside pipe.
- Typical Design Criteria
  - » Q = 2 – 5% of plant flow
  - » Gt = 400 – 1,600
  - » V = Mixing Zone L*D
    - – 0.5 – 2.0 Pipe Diameter
  - » Jet Velocity > 20 ft/s



$$G = \sqrt{\frac{P}{\mu V}}$$

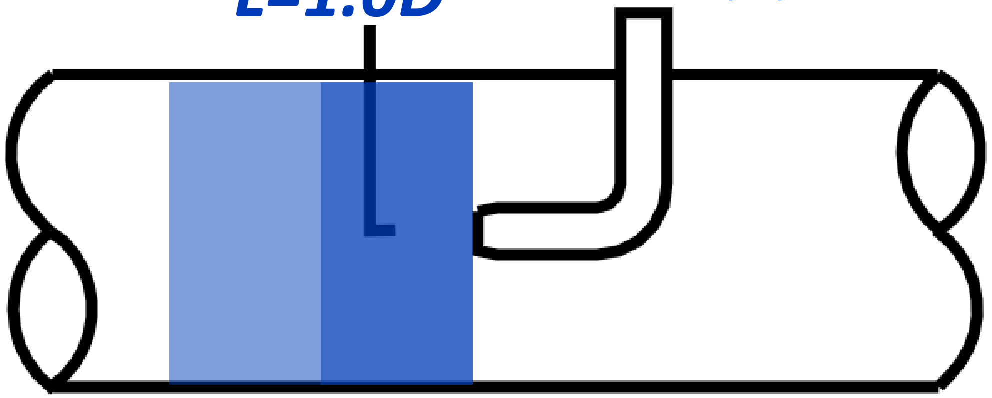
$$Gt$$

Pumped Diffusion – Variability in G



(for fixed pump flow)

$P = f(jet\ velocity) = f(pump\ flow)$



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$$G = \sqrt{\frac{P}{\mu V}}$$

$$Gt$$

Mechanical Mixing

- Mechanical mixer in tank or channel.
- Vertical shaft mixers similar to flocculation basins.
- Longer mixing time with potential for backmixing.
- High energy input required.
- Design Criteria:
  - » G = 300
  - » t = 10 – 30 seconds

$$G = \sqrt{\frac{P}{\mu V}} \qquad Gt$$

In-Line Mixing

- In-line motor driven impeller within pipe spool piece.
- More rapid mixing in smaller footprint (compared to in-tank).
- Some backmixing concerns.
- Design Criteria:
  - » G = 1,000 – 2,000
  - » t = < 5 seconds

$$G = \sqrt{\frac{P}{\mu V}} \qquad Gt$$

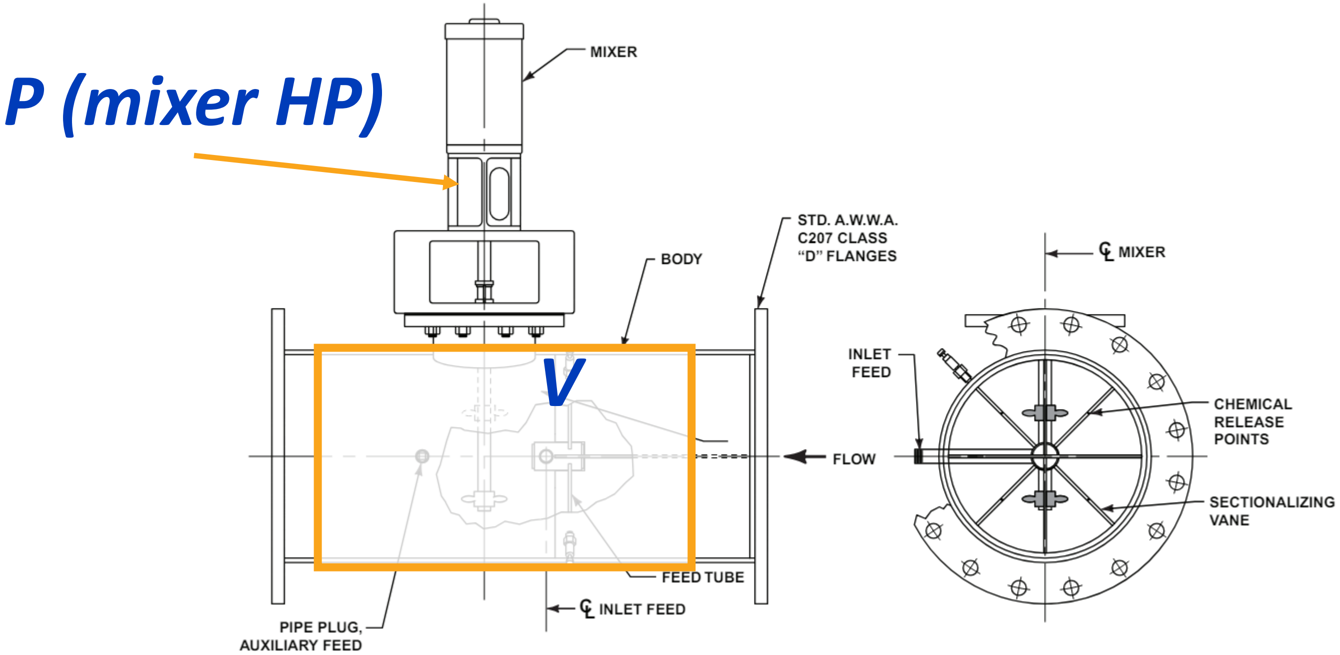


Image Source: Walker Process Equipment

03

Flocculation Technologies and G

Flocculation Technologies

- Purpose: Agitate fluid to promote aggregation of neutralized floc particles.
  - Limit energy input to prevent shearing floc.
  - Longer mixing time.

- Hydraulic Flocculation
- Horizontal Paddlewheel
- Vertical Paddlewheel
- Vertical Shaft / Turbine

Potential energy in the water (Hydraulic Flocculation)

External mechanical energy input (Horizontal Paddlewheel, Vertical Paddlewheel, Vertical Shaft / Turbine)

Hydraulic Flocculation

- Mixing achieved through turbulent head loss created by baffled channels.
- Large fluffy flocs.
- *Variable mixing energy based on flow rate.*
- Design Criteria
  - G = 10 – 50 sec^{-1} (tapered)
  - t = 30 – 45 minutes

$$G = \sqrt{\frac{P}{\mu V}}$$

$$Gt$$

Horizontal Paddlewheel

- Typically produces heavier, fluffier floc.
- Design Criteria
  - » G = 10 – 50 sec^{-1} (tapered)
  - » t = 30 – 40 minutes
  - » 2 – 6 flocculation stages

$$G = \sqrt{\frac{P}{\mu V}}$$

$$Gt$$

Vertical Shaft / Vertical Paddlewheel

- Vertical shaft most common.
- Typically produces smaller, denser floc.
- Design Criteria
  - $G = 20 – 80\ sec^{-1}$ (tapered)
  - $t = 30 – 40$ minutes
  - 2 – 4 flocculation stages

$$G = \sqrt{\frac{P}{\mu V}}$$

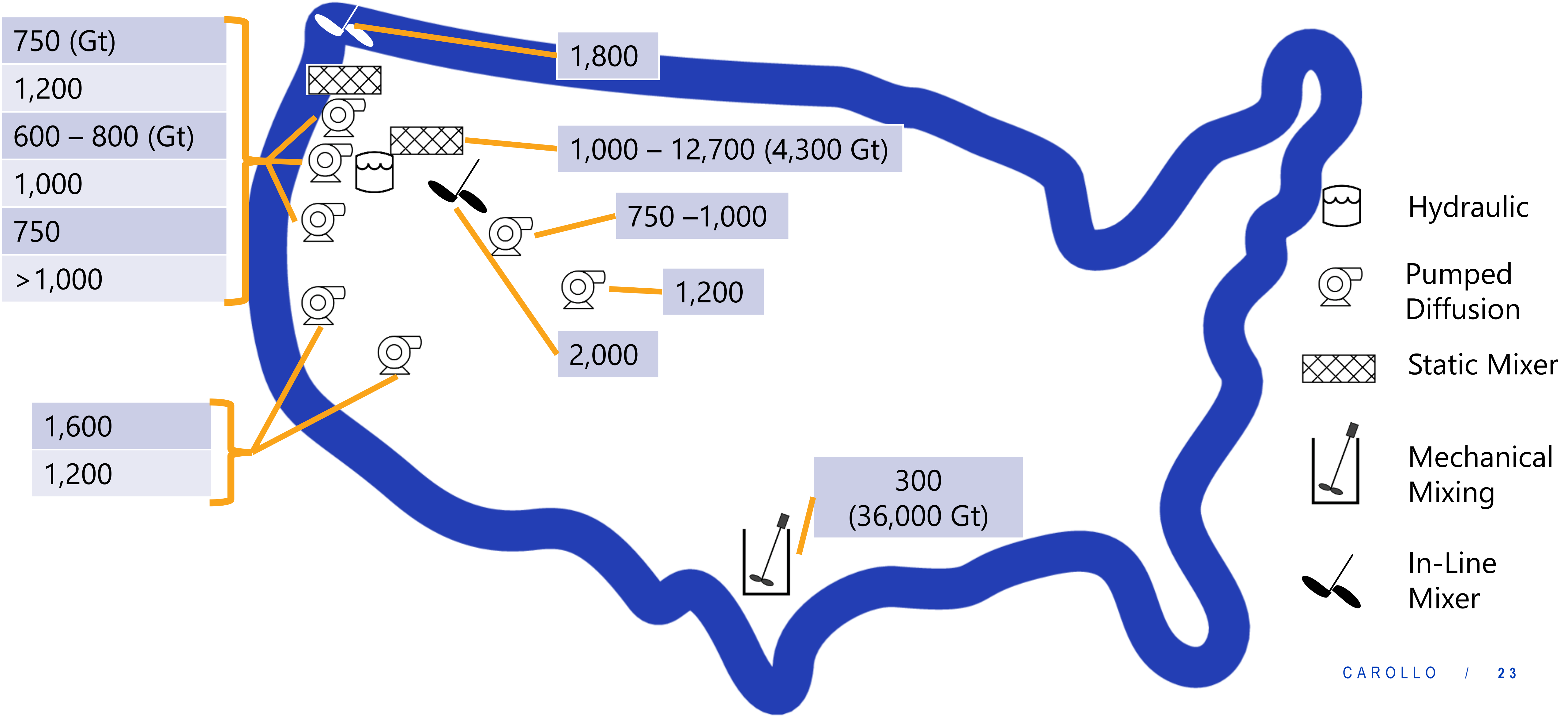
$$Gt$$

04

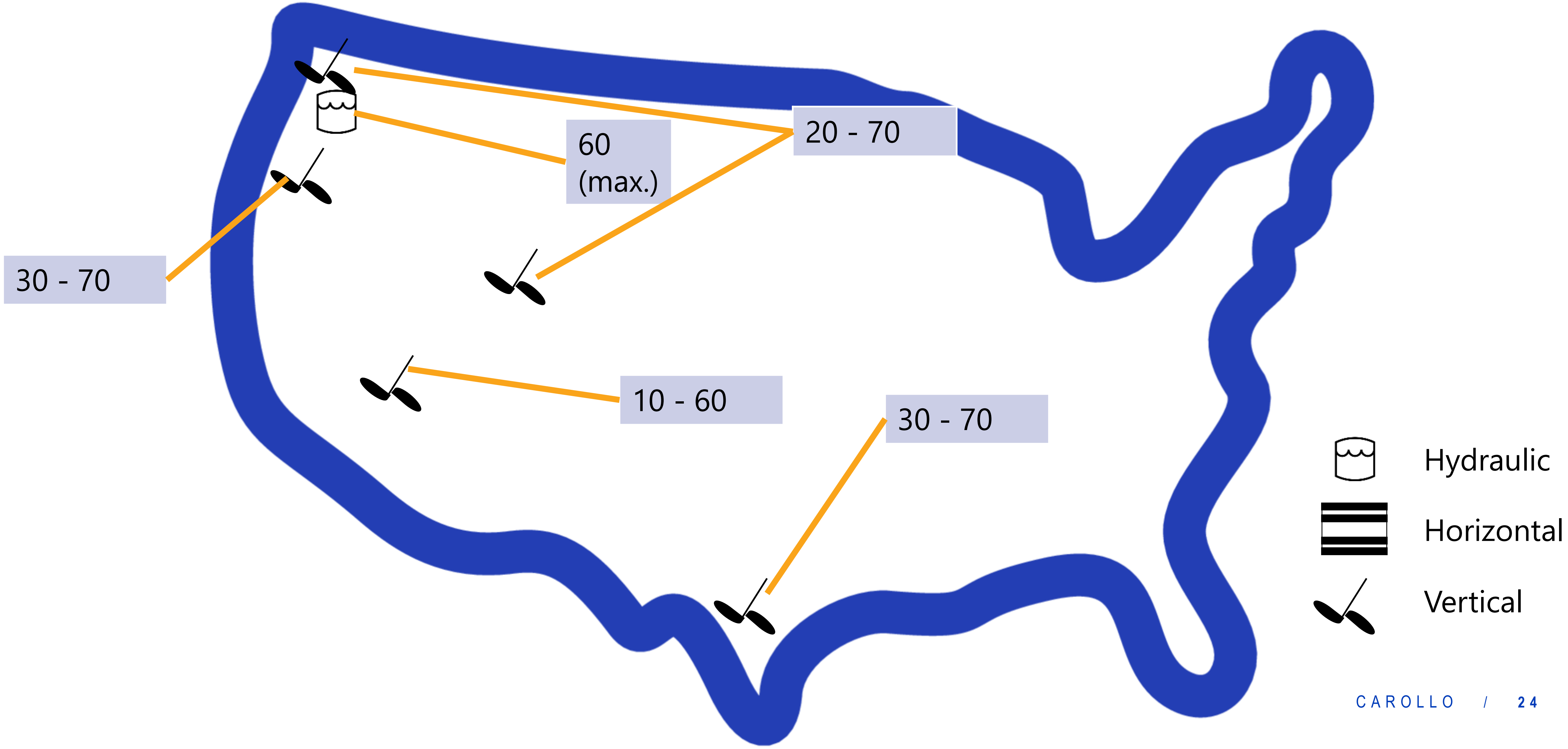
Review of Mixing Design Criteria at In-Service WTPs

carollo

Flash Mixing Design Criteria Comparison



Flocculation Technology Comparison



05 Summary

Takeaways

- Chemical mixing is fundamental to coagulation / flocculation process.
- Design relies on the more empirical G value due to complexity of characterizing mixing.
- Flash mixing G values range significantly based on selected mixing technology and across plants.
- Effective coagulation and flash mixing have been proven across a wide range of technologies and G values.
  - » Additional coagulant can mitigate lack of optimal mixing.

Questions?

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