Determining the G Values or Effectiveness of Chemical Diffusers and Injectors

One of the most common methods of measuring mixing, particularly the mixing of flocculants or coagulants is the use of “G value”. This term originally proposed by Camp and Stein (1943) refers to the mechanical power required to facilitate turbulent mixing and is based on the velocity gradient.

The mean velocity gradient G for mechanical mixing is:

$G = (P/\mu V)^{1/2}$ where

G = mean velocity gradient: velocity (ft/sec)/distance (ft) is equal to per second
P = power dissipated, ft lb/sec or N m/sec (W)
μ = absolute viscosity lb-s/ft^2 or N-s/m^2
(absolute viscosity for water at 60ºF is 2.35×10^{-5} lb s/ft^2)

V = volume of basin, ft^3 or m^3

It is generally recognized that the velocity gradient or G-value concept is a simplistic view that has not been shown to accurately correlate mixing effectiveness for different mixing processes. However, as a better method of measuring mixing has not been developed, G values continue to be discussed when discussing mixing intensity.

As an example, static mixers have a very intense mixing, however this mixing is uniformly applied during the single pass-through for all of the fluid and occurs when the chemicals have not fully reacted. The flocculant chains are in the form of “pin flocs”—fledgling chains, and can withstand the short duration of very high shear . This intense mixing (which would be on the order of 2,000-5,0000 sec^{-1} for less than 1 second) is very effective, yet is not anywhere close to the G value (35 sec^{-1} for 30 minutes) that is recommended for motor driven propeller mixers for flocculants and coagulants[1].

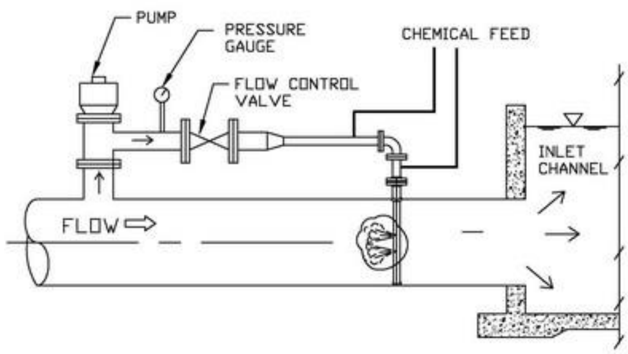
When analyzing Chemical diffusers for a G value, the diffuser can be treated as a jet mixing type of mixer. There are three components to this mixing:

- The mixing energy that is a result of the pressure drop as the chemicals exit the injector orifice. All of the power used to force the injected chemical through the injector becomes mixing energy.

- The pressure drop of the injector/ chemical diffuser body or pipe in the pipe flow

- If the jets are pointed upstream to create a counterflow and further diffusion, there is additional energy expended that further increases the G value.

Let's look at an example:



Chlorination of a pipeline is conducted using gaseous chlorine dissolved into a carry water stream of 50 gpm The18" diameter pipeline has a flow rate of 6 MGD (4,164 gpm). A 2" diameter full pipe diameter injector is being used with the orifice holes pointed upstream in a counter flow arrangement. The diffuser is designed for 25 ft/sec velocity out of the quantity (6) orifice holes for maximum diffusion.

Calculate Diffuser Orifice Hole Size
Using flow rate / velocity relationships, this results in an orifice size for each of the (6) orifice holes of 0.369 in.

Calculate Pressure drop across the chemical diffuser/ injector
With a flow of 50 gpm, the flow through each of the (6) holes = 8.3 gpm

Calculate Pressure drop across each orifice hole.
This is equivalent to a pressure drop of 11.3 psi (26.9 ft head) across the injector using orifice calculations.

Calculate the G factor from the flow through the diffuser

$$G = \sqrt{\frac{550xP}{\mu V}}$$

With:
P = power (hp) being dissipated in the mixing zone
μ = absolute viscosity (lb-sec/ft^2) and equals 2.735 x 10^{-5} at 50ºF and 2.05 x 10^{-5} at 70ºF
V = Volume of mixing zone (ft^3)

P = The power being dissipated in the mixing zone (hp) = $\frac{Qph}{60x550xeff}$

With:
Q= total injector discharge flow, gal/min
p = water density, lb/gal [approx. 8.34 lb/gal]
h = head loss through diffuser , ft
60 = sec/min
550 = ft-lb/sec/hp
Eff = system efficiency

P = $\frac{Qh}{3960}$ = $\frac{50 \text{ gpm x } 26.9 \text{ ft}}{3960}$ = 0.34 hp

To calculate G, the volume of the initial mixing area affected by the jet will have to be decided. Experience has demonstrated that mixing will occur in 2-3 sec. Assuming 2 seconds for mixing, at a flow rate of 6 MGD (4,164 gpm),

where v = 5.24 ft/sec

Results in a mixing volume of 18.5 ft^3

Consequently:

G = $\sqrt{\frac{550x0.34}{2.35x10^{-5}x18.5}}$ = 655

Calculate the Velocity Gradient of the Diffuser Restriction

The next step is to account for the diffuser restriction, which both cause a pressure drop and result in an increase in the velocity of the main stream as the flow in the pipeline has to increase velocity to momentarily pass by the diffuser pipe. This increases the velocity *v* from 5.24 ft/sec to 6.1 ft/sec, based upon the decrease in area.

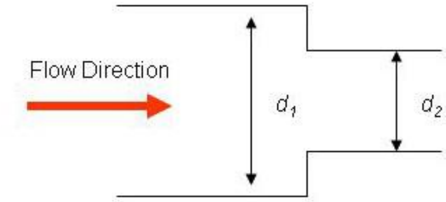
And using a variation on the Darcy formula:

Head Loss (foot) $h_L = K\frac{v^2}{2g}$

where:
K = Resistance Coefficient or velocity head loss
v = velocity (ft/sec)

g = gravitation constant of 32.17 ft/sec^2

Assumption:
K factor for the flow resistance of the Injector can be approximated as a sudden contraction in pipe diameter equal to area equivalent of the frontal area of the injector in the pipeline



K is estimated at K = 0.5 $\left(1-\frac{d_1}{d_2}\right)$ *Crane Flow of Fluids Technial Paper No. 410 Equation 2-10*

And d_1 = $\sqrt{d_2^2-\frac{4}{\pi}(d_i d_2)}$ d_1 = $\sqrt{18^2-\frac{4}{\pi}(18\cdot 2)}$ = 16.7 in

where d_i = injector diameter

Then:

K = 0.5 $\left(1-\frac{16.7}{18}\right)$ = 0.036

Then:

h_L = K $\frac{v^2}{2g}$ = 0.036 $\frac{6.1^2}{2\cdot 32.17}$ = 0.021 ft

P = $\frac{4164x8.34x0.021}{60x550}$ = 0.021 hp

And therefore G = $\sqrt{\frac{550\cdot 0.02}{2.5x10^{-5}\cdot 18.5}}$ = 161 sec^{-1}

Velocity Gradient of Contraflow Effect

The next step is to calculate the additional G for the energy dissipation that occurs by directing the diffuser flow against the pipeline flow.

We convert the velocities of both the pipeline flow and opposing injector jet flow to a velocity head
h_p = pipeline head (ft) = 0.43 ft
h_j = injector jet head (ft) = 9.7 ft

Convert velocity heads to energy by assuming that the mixing occurs within one second time.

Pounds of water imparted by diffusion jet:

50 gpm x $\frac{1\,\text{min}}{60\,\text{sec}}$ x 8.34 lb/gal = 6.95 lb/sec

Pounds of water imparted by diffuser body

4164 gpm x $\frac{1\,\text{min}}{60\,\text{sec}}$ x 8.34 lb/gal = 578 lb/sec

Determine energy of both streams:
Energy = velocity head x lb water/sec

Diffuser jet energy:
E_j = 9.7 ft x 6.95 lb/sec = 67 ft-lb/sec

Diffuser body energy:
E_p = 0.43 ft x 578 lb/sec = 249 ft-lb/sec

Net energy available for mixing
$E_M = E_P + E_J$

=67 ft-lb/sec + 249 ft-lb/sec =316 ft-lb/sec

Convert to hp:

$$\frac{316\ \text{ft - lb/sec}}{550} = 0.57\ \text{hp}$$

$$G_c = \sqrt{\frac{550x0.57}{2.5x10^{-5}x9.2}} = 1{,}167\ \text{sec}^{-1}$$

Total G Value for the Injector
Summing up the G factors for:

1) Pressure drop across the orifice holes (655 sec^{-1})

2) Pressure drop due to diffuser restriction (161 sec^{-1})
3) Velocity Gradient of Contraflow Effect (1167 sec^{-1})

G_{total} = 655 + 161 + 1167 = 1983 sec^{-1}

[1]Integrated Design and Operation of Water Treatment Facilities, Susumu Kawamura p. 21 2nd edition 2000