Optimizing Mix Performance – An Update

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Optimizing Mix Performance

Mixing - The reduction in inhomogeneity to achieve a desired process result

Inhomogeneity can be due to variations in concentration, phase, and/or temperature.

For coating, typically, our objective is uniformity of coated product, so our mixing focus is on uniform concentration
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Mixing is used in a wide variety of processes

- Blending of miscible liquids in tanks (batch process)
- Blending of miscible liquids in-line
- Dispersion of gases in liquids
- Suspension and dispersion of solids in liquids
- Immiscible liquid dispersions
- Heat transfer
- Reactions

Handbook of Industrial Mixing
In this paper, measurement techniques to characterize an existing tank and agitator will be discussed.

A general view of the relationship of mix parameters will be developed.

Finally, a calculation method to evaluate a new fluid in an existing tank will be shown.

Highlights from 2008 AIMCAL FTC
There are several methods to characterize the mixing performance of a batch tank and agitator.

- Visual observation
- Decolorization observation
- Sampling
- Monitors in the tank
Optimizing Mix Performance

There are several methods to characterize the mixing performance of a batch tank and agitator.

- Visual observation (no estimate of mix time)
- Decolorization observation (estimate of mix time)
- Sampling (quantitative mix time)
- Monitors in the tank (quantitative mix time)

Aim is to determine what is happening in the mix tank.
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Flow Visualization

- Do first
- Observations direct subsequent sample points and measurements
- Light sheet
- Reflective particles
- Recording method
- If not practical, go to decolorization methods
Flow Visualization using streak photography

Figure 4-11 (from Handbook of Industrial Mixing, p.166)
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Sampling

- Sampling procedure is usually difficult.
- Analysis of samples is required for data, e.g., concentration.
- May be only choice available
- Not good for very short mixing times
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Monitors in the Tank

- Position of placement is critical
- Use at least three probes
- Shape of monitor has to have minimal effect on flow pattern
- pH probes or conductivity probes best
- Collect data over time, well past well-mixed point
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Probe Position Diagram

Probes 1, 2, 3
Use normalized probe output:

$$C'i = \frac{(C_i - C_0)}{(C_{\text{inf}} - C_0)}$$

Normalized Measurement Data from Probes

Figure 4-16  (from Handbook of Industrial Mixing, p.173)
Optimizing Mix Performance

\[ \log \text{var}^2 = \log (C'_t - 1)^2 \]

\[ \log \text{var}^2_{\text{RMS}} = \log \left\{ \frac{1}{3} [ (C'_{t,1} - 1)^2 + (C'_{t,2} - 1)^2 + (C'_{t,3} - 1)^2 ] \right\} \]

Fig. 4-17 (from CD accompanying Handbook of Industrial Mixing)
Optimizing Mix Performance

- For 95% mixing time, $C' = 0.95$
  
  $\log \text{var}^2 = \log(0.95-1)^2 = \log 0.0025$
  
  $= -3 + 0.398$
  
  $= -2.602$

Mixing time = 33 sec from Fig. 4-17

Assuming a linear relationship of mixedness ($\log \text{var}^2$) and time, we can estimate mixing time for any degree of mixedness, $n$, by the following:

$$\frac{\text{mix } t_n}{\text{mix } t_{95}} = \frac{\log[1-(n/100)]}{\log(1-0.95)}$$
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Relationship of Mix Parameters

- Video of Effect of Baffle (from CD accompanying Handbook of Industrial Mixing)
- Impeller Reynolds number
- Goal is to estimate mix time by calculation
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Relationship of Mix Parameters

Reynolds number for mixing

- $Re = \frac{pUd}{u}$ for flow in a pipe of diameter $d$
- 0-2000 (laminar); 2000-4000 (transition); >4000 (turbulent)

- Impeller $Re = \frac{ND^2p}{u}$ for mixing tanks where $N$ is impeller speed, rev/sec, and $D$ is impeller length, m
  - 0-50 (laminar); 50-5000 (transition); >5000 (turbulent)
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Relationship of Mix Parameters

Impeller Reynolds Number

- Typical $\rho$ – 1000 kg/m$^3$
- Typical $N$ – 1 rps
- Typical $D$ – 1 m
- Typical $u$ - 0.01 Pa-sec (10 cp)
- For this set of conditions, $Re=100,000$
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Relationship of Mix Parameters

Nominal Tank Dimensions
\[ D = 0.4T - 0.6T \]
\[ H = 0.8T - 2T \]
\[ T = 0.4 - 3.0 \text{ m} \]
Optimizing Mix Performance

Relationship of Mix Parameters

Grenville Correlation

- Impeller turbulent regime \((Re_{impeller} > 5000)\)
- Standard Baffles (~0.1T)
- One impeller, at 1/3 H

\[
(P_o)^{1/3}N[\text{mix time}]D^2/(T^{1.5}H^{0.5}) = 5.2 \ (1\sigma = +/-10\%)
\]

for many combinations of impeller shape, impeller speed, impeller size, tank size, and tank level
Optimizing Mix Performance

Relationship of Mix Parameters

Grenville Correlation

- Impeller transitional regime \((50 < \text{Re}_{\text{impeller}} < 5000)\)
- Standard Baffles \((\sim 0.1T)\)
- One impeller, at 1/3 H
- \((P_o)^{2/3}N[\text{mix time}]\text{Re}(D^2/T^2) = 33,489\)

for many combinations of impeller shape, impeller speed, impeller size, tank size, and tank level. Non-Newtonian fluids need special attention
Optimizing Mix Performance

New Fluid in Existing Tank – Determine Mix Time

\[ Re = \frac{N D^2 p}{u} ; \quad N=1 \ rps; \quad D=1 \ m; \quad p=980 \ kg/m^2; \quad u = 100 \text{cp} = 0.1 \text{ Pa-sec} \]

\[ Re = 9800 \rightarrow \text{turbulent} \]
New Fluid in Existing Tank - Determine Mix Time Using Grenville Correlation

- Impeller turbulent regime ($Re_{impeller} > 5000$)
- One impeller, at 1/3 H
- Standard Baffles (~0.1T)
- $P_o^{1/3}N[mix\ time]D^2/(T^{1.5}H^{0.5}) = 5.2$
- For $P_o$ of 1.8, N of 1 rps, D of 0.5T, H=T, we get:
  \[
  [mix\ time] = \frac{5.2}{[1.8^{1/3}1*(0.5T)^2/T^2]}
  = \frac{5.2}{1.2*1*0.25} = \frac{5.2}{0.3}
  = 17\ sec
  \]
- For design, use 3σ limit of constant, 5.2 → 6.8, and
  \[
  [mix\ time] = 23\ sec
  \]
Conclusions from Analysis of Grenville Correlation

- All impellers of the same diameter are equally energy efficient (same mix time at the same power per unit mass of fluid).
- A larger impeller diameter will achieve a shorter mix time for the same power input per unit mass.
- Mix time is independent of the fluid’s physical properties in the turbulent regime.
- When scaling up at constant power per unit mass and constant geometric ratios, mix time will increase by the [scale factor]$^{2/3}$.

(Handbook of industrial Mixing, p.511)
Mixing Update

3 Recent articles in Chemical Engineering Progress

- “Select the Right Impeller”; Julian B. Fasano; June, 2015
- “When Mixing Matters: Choose Impellers Based on Process Requirements”; Marcio B. Machado and Suzanne M. Kresta; July, 2015
- “Tackling Difficult Mixing Problems”; David S. Dickey; August, 2015
“Select the Right Impeller”
First, for mixing miscible fluids, impeller choice is dependent on:

- Fluid regime (turbulent, transitional, or laminar)
- Impeller Re #
- Ratio of liquid height to tank diameter (H/T)
Optimizing Mix Performance

Relationship of Mix Parameters

Reynolds number for mixing

- $Re = \rho Ud / u$ for flow in a pipe of diameter $d$
- 0-2000 (laminar); 2000-4000 (transition); >4000 (turbulent)
- Impeller $Re = ND^2 \rho / u$ for mixing tanks where $N$ is impeller speed, rev/sec, and $D$ is impeller length, m
  - 0-10 (laminar); 10-2500 (transition);
  - >2500 (turbulent) [was 0-50; 50-5000; >5000]
Optimizing Mix Performance

Relationship of Mix Parameters

Impeller Reynolds Number

- Typical $\rho$ – 1000 kg/m$^3$
- Typical $N$ – 1 rps
- Typical $D$ – 1 m
- Typical $u$ - 0.01 Pa-sec (10 cp)
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Optimizing Mix Performance

Relationship of Mix Parameters

Nominal Tank Dimensions

\[ D = 0.4T - 0.6T \]
\[ H = 0.8T - 2T \]
\[ T = 0.4 - 3.0 \text{ m} \]
<table>
<thead>
<tr>
<th>Fluid Regime</th>
<th>Reynolds No.</th>
<th>H/T</th>
<th>Impeller Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbulent</td>
<td>&gt; 2,500</td>
<td>≤ 1.50</td>
<td>High-efficiency axial-flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 0.50</td>
<td>High-efficiency axial-flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High-efficiency radial-flow</td>
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<tr>
<td>Transitional</td>
<td>500–2,500</td>
<td>&lt; 0.75</td>
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<td></td>
<td></td>
<td></td>
<td>Pitched-blade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 0.33</td>
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</tr>
<tr>
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<td></td>
<td>Paddle</td>
</tr>
<tr>
<td></td>
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<td>&lt; 0.50</td>
<td>Pitched-blade</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wide-blade hydrofoil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 0.33</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Paddle</td>
</tr>
<tr>
<td>Laminar</td>
<td>&lt; 10</td>
<td>&lt; 0.50</td>
<td>Anchor</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Helical ribbon</td>
</tr>
<tr>
<td></td>
<td>≥ 0.50</td>
<td></td>
<td>Helical ribbon*</td>
</tr>
</tbody>
</table>

*An auger impeller could also be used if little or no heat transfer through the vessel wall is required.*
Mixing Update

Lightnin A310 High-Efficiency Axial-Flow Impeller

Chemineer BT-6 High-Efficiency Radial-Flow Impeller

Wide-Blade Hydrofoil Chemineer Maxflo W Impeller
Mixing Update

- Pitched Blade Impeller
- Paddle Impeller
- Anchor Impeller
- Helical Ribbon Impeller
“Select the Right Impeller”
Second, for suspending solids, impeller choice is likewise dependent on:

- Fluid regime (turbulent, transitional, or laminar)
- Impeller Re #
- Ratio of liquid height to tank diameter (H/T) but (H/T) limits are slightly different.
Table 2. Recommended impellers for solids suspension.

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“When Mixing Matters: Choose Impellers Based on Process Requirements”

Based on Machado’s work, the five key performance measures for impellers:

- Power consumption
- Bulk flow
- Local turbulence at the impeller
- Turbulence at the vessel bottom
- Conditions at the liquid surface
“Choose Impellers Based on Process Requirements” examines two case studies (mixing in suspension polymerization; and scaling down a pipeline mixing process), showing how the performance measures can be used to specify an impeller and a process to achieve desired results There are significant calculations involved.
Mixing Update

“Tackling Difficult Mixing Problems”

- Difficult problems discussed: Non-Newtonian behavior (often when viscosity >1000 cp); powder addition; and emulsification.

- For non-Newtonians, use large and/or multiple impellers

- In powder addition processes, use longer mix times; improve wetting by adding surfactant; control rate of addition; some, but not too much, vortex
Mixing Update

- For emulsification, need high shear and often stabilizer.
- Because of energy added, monitor and control temperature.
“Tackling Difficult Mixing Problems”

- Misunderstandings about mixing: Vortex not necessarily good - eliminate with baffles; Miscibility and viscosity - add high visc to low visc fluid

  Scale-up - small scale for key variables and accurate measurements to id success
“Tackling Difficult Mixing Problems”

- Obstacles to improvement – biggest is using existing equipment – requires creativity
  - Change order of addition
  - Add minor ingredients to the less-viscous material
  - Use different ingredients
  - Reduce batch size
  - Modify equipment - consider multi-shaft mixing vessels
Mixing always obeys physical laws’
- Even when we want it not to
Mixing Update

Update to Handbook of Industrial Mixing
5 rewritten and updated fundamentals chapters
6 new chapters of recent industrial applications
Updated DVD with 20 tutorials, along with new video clips and animations of mixing processes
Available in November, 2015
Optimizing Mix Performance

Thank You