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

Optimizing Mix Performance

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

Optimizing Mix Performance

- 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.

Optimizing Mix Performance

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.

Optimizing Mix Performance

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

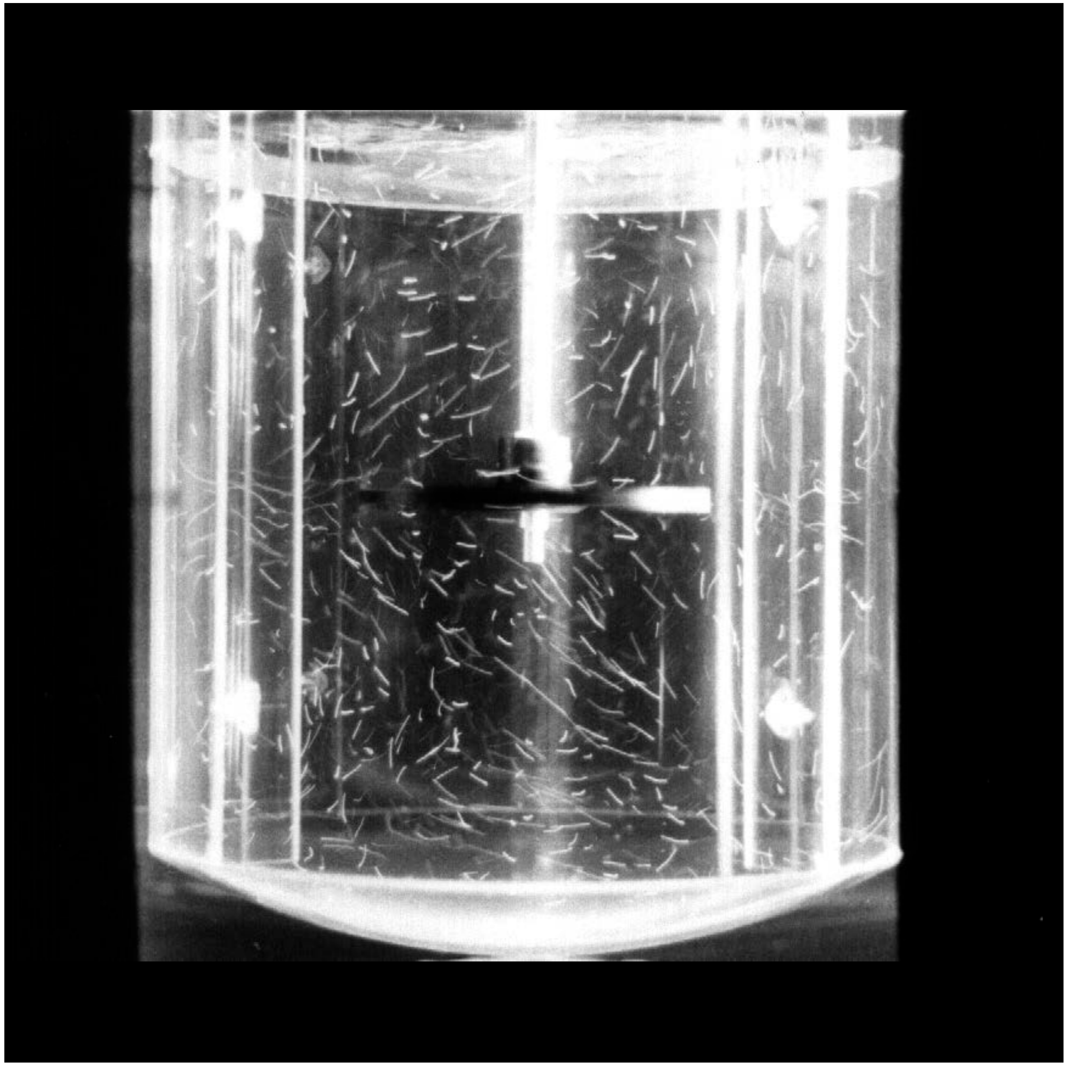


Figure 4-11 (from Handbook of Industrial Mixing, p.166)

Optimizing Mix Performance

Sampling

- Sampling procedure is usually difficult.
- Analysis of samples is required for data, eg., concentration.
- May be only choice available
- Not good for very short mixing times

Optimizing Mix Performance

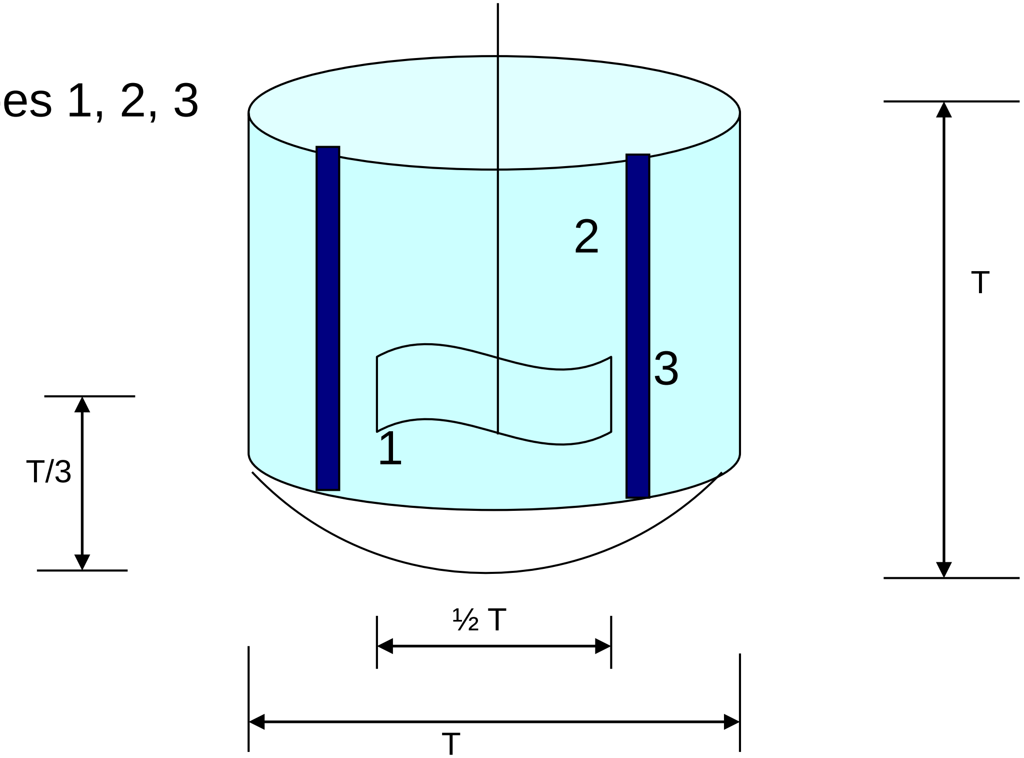
Monitors in the Tank

- 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

Optimizing Mix Performance

Probe Position Diagram

Probes 1, 2, 3



Normalized Measurement Data from Probes

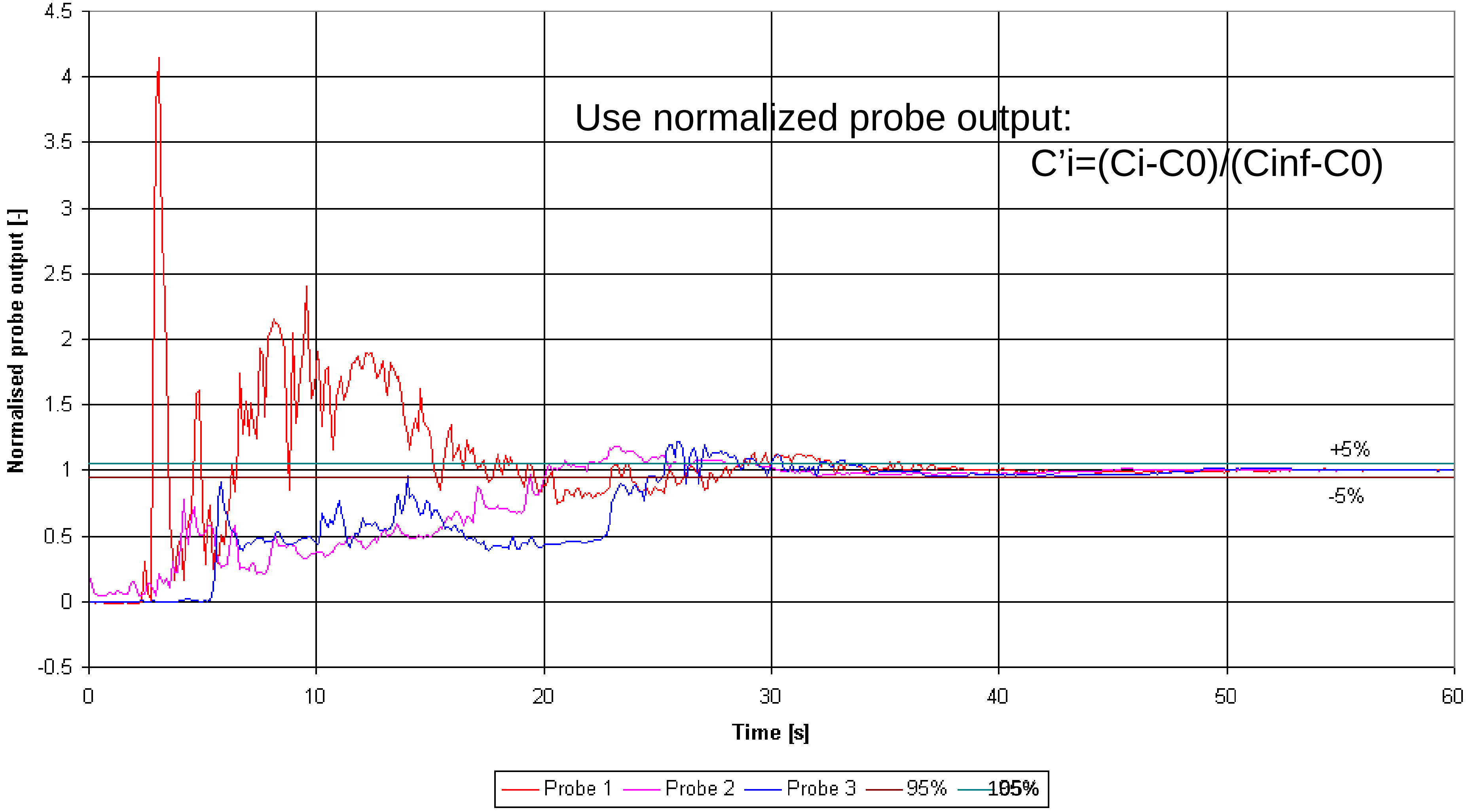
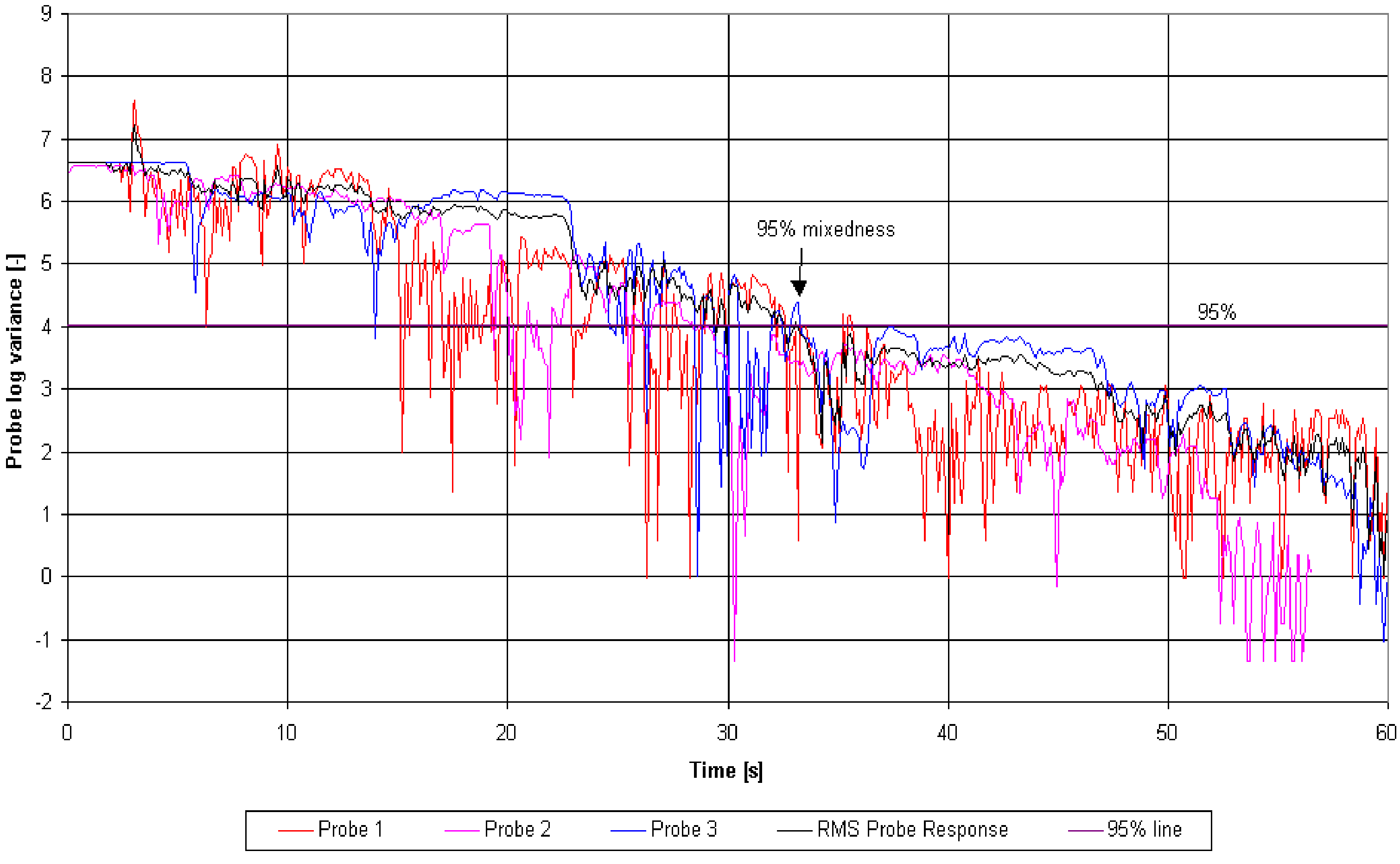


Figure 4-16 (from Handbook of Industrial Mixing, p.173)

Optimizing Mix Performance



$\log var^2 = \log(C'_t - 1)^2$ $\log var^2_{RMS} = \log\{1/3[(C'_{t,1}-1)^2 + (C'_{t,2} - 1)^2 + (C'_{t,3} - 1)^2]\}$

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

Optimizing Mix Performance

- For 95% mixing time, C' = 0.95

 $\log var^2 = \log(0.95-1)^2 = \log 0.0025$

 $= -3+0.398$

 $= -2.602$

Mixing time ⇨ 33 sec from Fig. 4-17

Assuming a linear relationship of mixedness

($\log var^2$) and time, we can estimate mixing time for any degree of mixedness, n, by the following:

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

Optimizing Mix Performance

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

Optimizing Mix Performance

Relationship of Mix Parameters

Reynolds number for mixing

- Re = *p*Ud/*u* for flow in a pipe of diameter d
- 0-2000 (laminar); 2000-4000 (transition);

  >4000 (turbulent)
- Impeller Re = $ND^2 p/u$ for mixing tanks where N is impeller speed, rev/sec, and D is impeller length, m

  0-50 (laminar); 50-5000 (transition);

  >5000 (turbulent)

Optimizing Mix Performance

Relationship of Mix Parameters

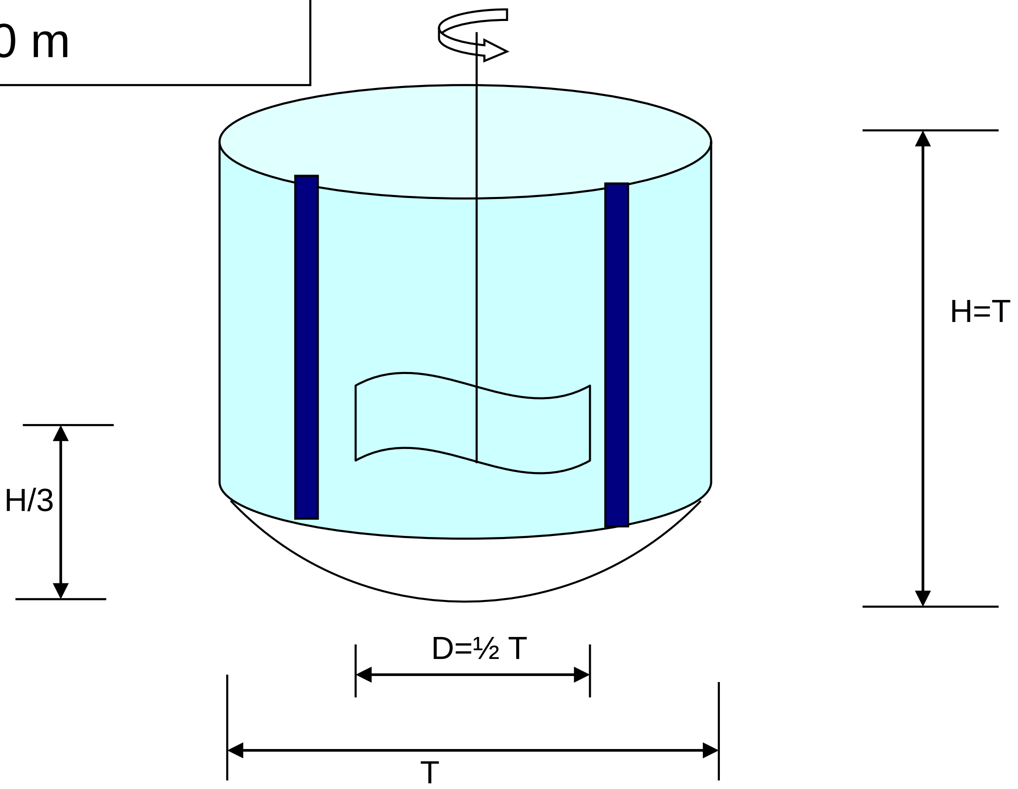
Impeller Reynolds Number

- Typical *p* – 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

Optimizing Mix Performance

Relationship of Mix Parameters

Nominal Tank Dimensions
D = 0.4T – 0.6T
H = 0.8T – 2T
T = 0.4 – 3.0 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
- $(P_o)^{1/3}N[\text{mix time}]D^2/(T^{1.5}H^{0.5}) = 5.2$ (1σ = +/-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

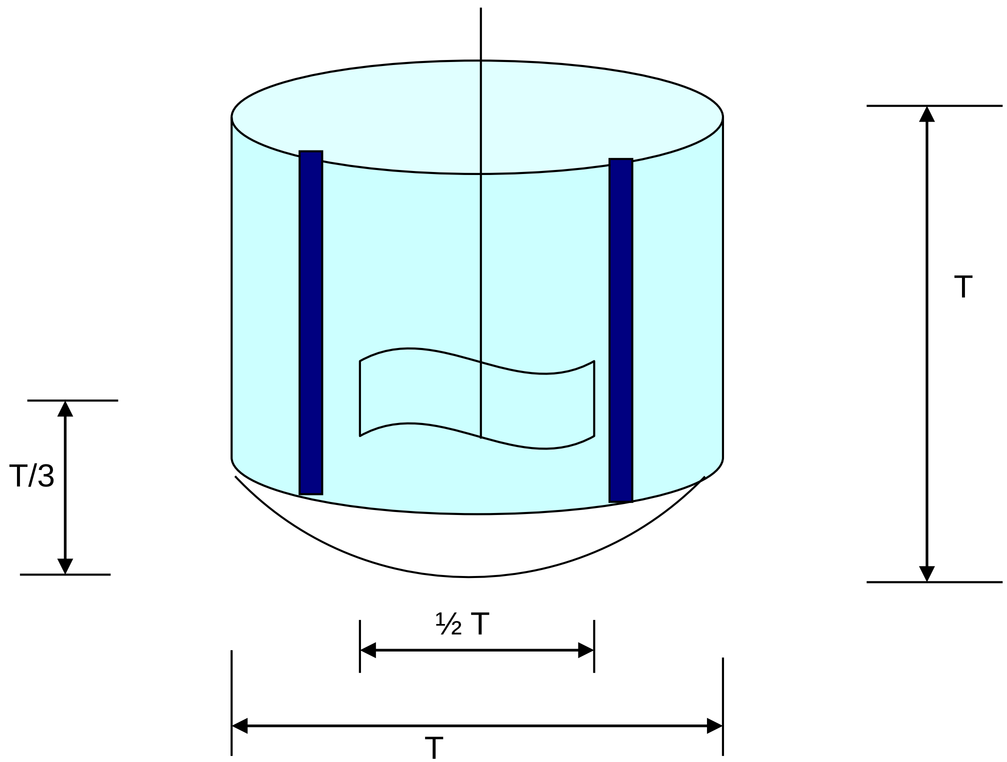
- Impeller transitional regime ($50<Re_{impeller}<5000$)
- Standard Baffles (~0.1T)
- One impeller, at 1/3 H
- $(P_o)^{2/3}N[\text{mix time}]Re(D^2/T^2) = 33{,}489$

  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= ND^2*p*/*u* ; N=1 rps; D=1 m; *p*=980 kg/m2; *u* = 100cp = 0.1 Pa-sec
Re = 9800 ⟶ turbulent



Optimizing Mix Performance

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)
- $P_o^{1/3}N[\text{mix time}]D^2/(T^{1.5}H^{0.5}) = 5.2$
- For P_o of 1.8, N of 1 rps, D of 0.5T, H=T, we get:

$[\text{mix time}] = 5.2/[1.8^{1/3}*1*((0.5T)^2/T^2)]$

$= 5.2/[1.2*1*0.25] = 5.2/0.3$

$= 17$ sec

For design, use 3σ limit of constant, 5.2 → 6.8, and [mix time] = 23 sec

Optimizing Mix Performance

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

Mixing Update

"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 = *p*Ud/*u* for flow in a pipe of diameter d
- 0-2000 (laminar); 2000-4000 (transition); >4000 (turbulent)
- Impeller Re = $ND^2 p/u$ 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 *p* – 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

Optimizing Mix Performance

Relationship of Mix Parameters

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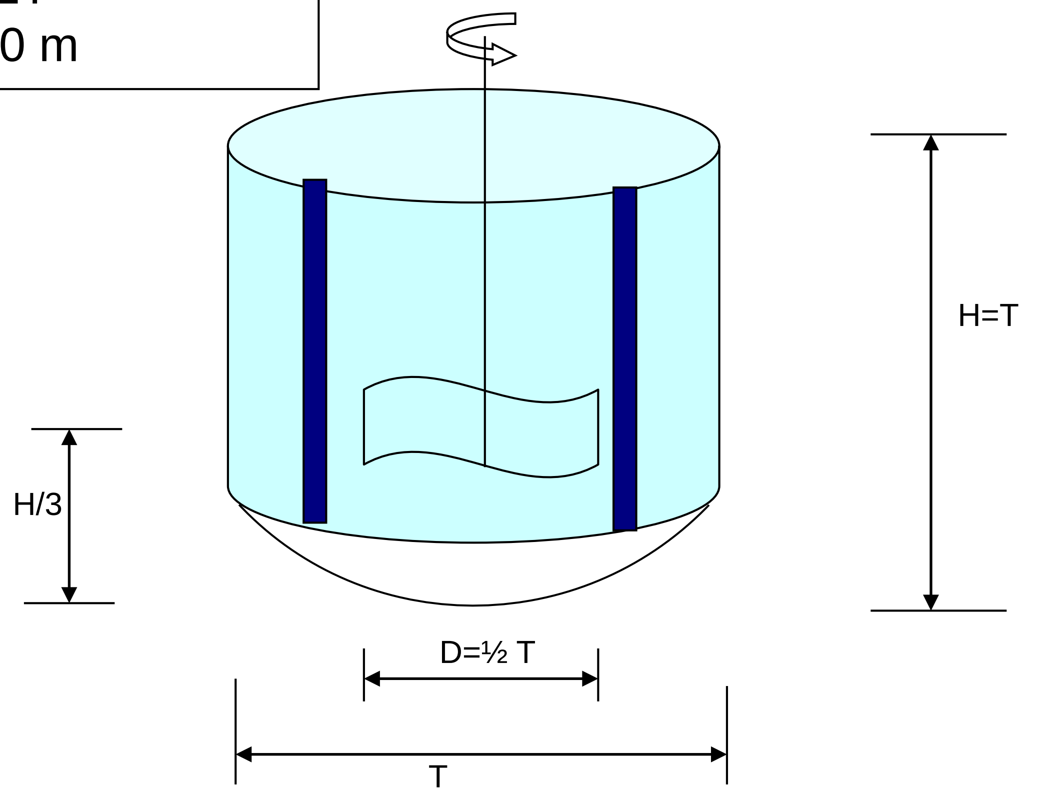


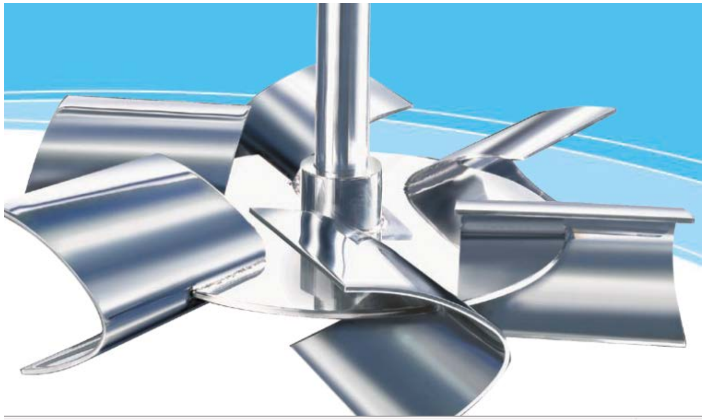
Table 1. Recommended impellers for miscible fluid blending.

Fluid Regime	Reynolds No.	*H/T*	Impeller Class
Turbulent	> 2,500	≤1.50	High-efficiency axial-flow
		< 0.50	High-efficiency axial-flow High-efficiency radial-flow
Transitional	500–2,500	< 0.75	High-efficiency axial-flow Pitched-blade
		< 0.33	High-efficiency axial-flow High-efficiency radial-flow Pitched-blade Paddle
	10–500	< 0.50	Pitched-blade Wide-blade hydrofoil
		< 0.33	Pitched-blade Paddle
Laminar	< 10	< 0.50	Anchor Helical ribbon
		≥0.50	Helical ribbon*

*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



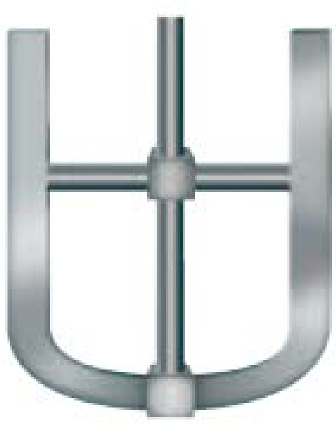
Chemineer BT-6 High-Efficiency
Radial-Flow Impeller

Wide-Blade Hydrofoil
Chemineer Maxflo W Impeller

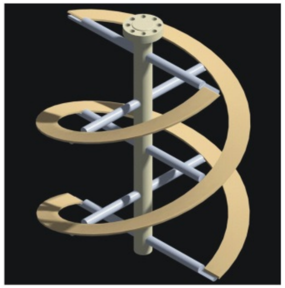
Mixing Update

Pitched Blade
Impeller

Paddle Impeller



Anchor Impeller



Helical Ribbon
Impeller

Mixing Update

"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.			
Fluid Regime	**Reynolds No.**	***H/T***	**Impeller Class**
Turbulent	> 2,500	≤1.00	High-efficiency axial-flow
		< 0.33	High-efficiency axial-flow High-efficiency radial-flow
Transitional	500–2,500	< 0.50	High-efficiency axial-flow Pitched-blade
		< 0.33	High-efficiency axial-flow High-efficiency radial-flow Pitched-blade Paddle
	10–500	< 0.50	Pitched-blade Wide-blade hydrofoil
		< 0.33	Pitched-blade Paddle

Mixing Update

"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

Mixing Update

“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.

Mixing Update

"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

Mixing Update

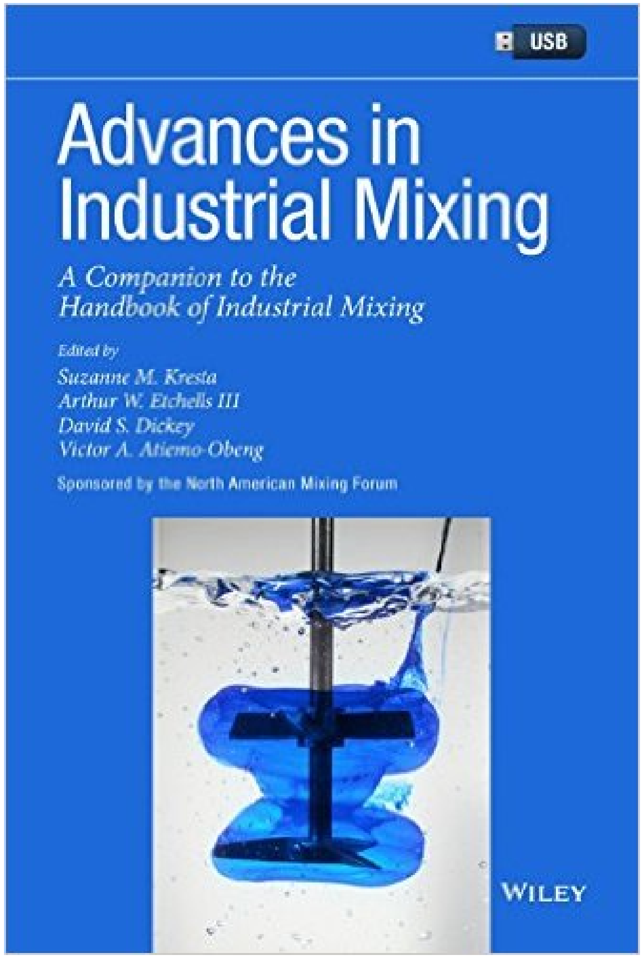
"Tackling Difficult Mixing Problems"

- 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 Update

- 'Mixing always obeys physical laws'
  - Even when we want it not to

Mixing Update



Update to <u>Handbook of Industrial Mixing</u>
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