Optimizing Mix Performance

AIMCAL Fall Technical Conference
October 19-23, 2007 – Myrtle Beach, SC

Clean Room Coating
Solutions

Dr. Kenneth McCarthy
President
Clean Room Coating Solutions
151 Flint Locke Drive
Duxbury, MA 02332
617-549-4620(C)
kenclnrm@prodigy.net
Website: www.cleanroomcoatingsolutions.com

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
- 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

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

Optimizing Mix Performance

- Part of a sample batch sheet for a fictitious, but typical, coating solution is shown on the next slide.
- Note the mix times for several of the steps, shown in red.
- There are several more additions after this section of the batch sheet.
- The total batch preparation time is 12 hours, with the bulk of that being mix time.

Optimizing Mix Performance

Sample Batch

	Mix 14301, Batch 12	Time Completed
1	Add 1500 L of DI H2O to Vessel D301	
2	Set Temp to 42°C, Jacket limit to 60	
3	Adjust pH to 5.30+/-0.05	
4	Mix for 30 minutes	
5	Add 500 L of Polymer ABC solution, Lot 1401	
6	Mix for 60 minutes at 60 rpm	
7	Add 3 kg of TiO2, Lot 15, slowly over 15 minutes	
8	Mix for 60 minutes at 60 rpm	

Optimizing Mix Performance

- For coating, a bad coating fluid hardly ever can be made ok by coating adjustments.
- On the other hand, in coating plants, overmixing increases labor costs significantly.
- Achieving the right balance of effective mixing and mix times just long enough is the goal

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

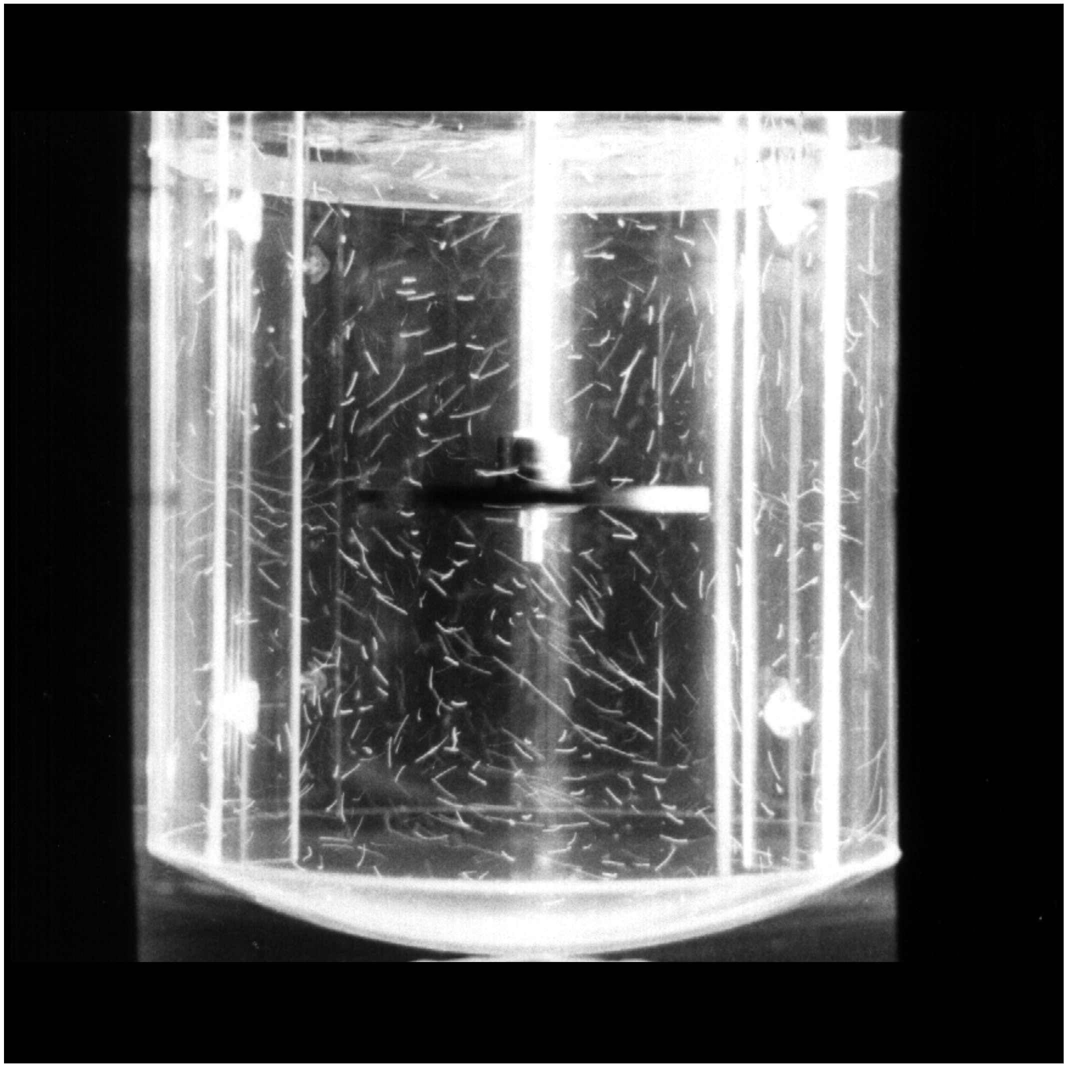


Figure 4-11 (from Handbook of Industrial Mixing, p.166)

Optimizing Mix Performance

Decolorization Observation

- Decolorization better than colorization
- Need a rheological model fluid close to actual fluid
- Put colorant into tank, eg., phenolphthalein or bromophenol blue, and mix well.
- Can use acid or base with appropriate indicator, then add slight excess of stoichiometric amount of opposite base or acid and observe color change

Optimizing Mix Performance

Decolorization Observation

- Alternative colorant system is iodine/thiosulphate with starch
- Starch first, then iodine to develop color
- Use thiosulphate to clear the color
- Observe the tank as clearing takes place to see where color is most apparent as it clears
- Estimate of mix time is when color is gone
- Additional experiments can be done by recharging system with starch, then iodine, then repeating

see Handbook of Industrial Mixing, p.169

Optimizing Mix Performance

Decolorization Observation

- Areas of last color change are least well mixed – check around baffles carefully.
- Photographic observation is useful.
- Good qualitative estimate of mix time can be made with careful observation.
- In many cases, this estimate is sufficient.

Optimizing Mix Performance

Decolorization Observation

- Several tests can be done with one batch charge.
- To return a ph color change after a test, add an aliquot of acid or base to return the full color with a slight excess. Bench scale tests can help quantify the amount.
- Rerun the test as a duplicate or with a new condition, say a different impeller speed

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

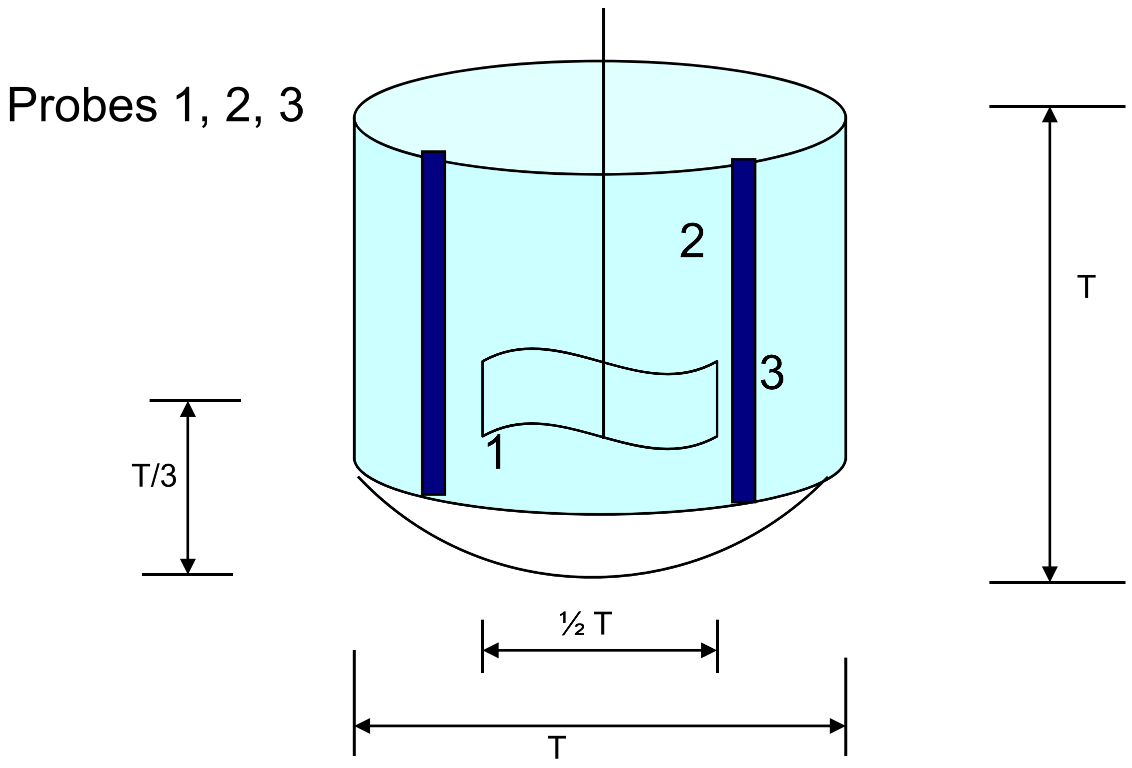
Optimizing Mix Performance

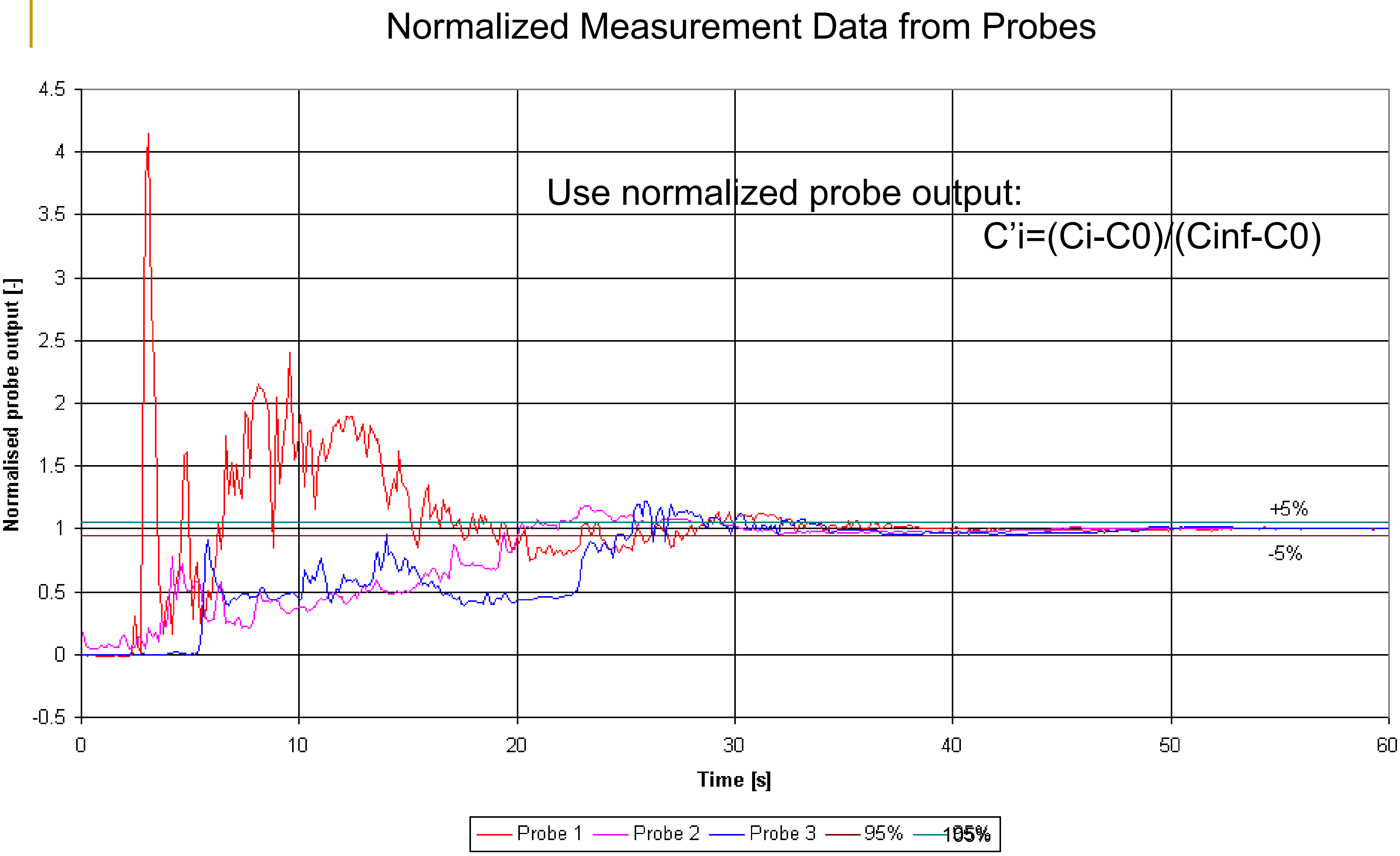
Monitors in the Tank

- 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



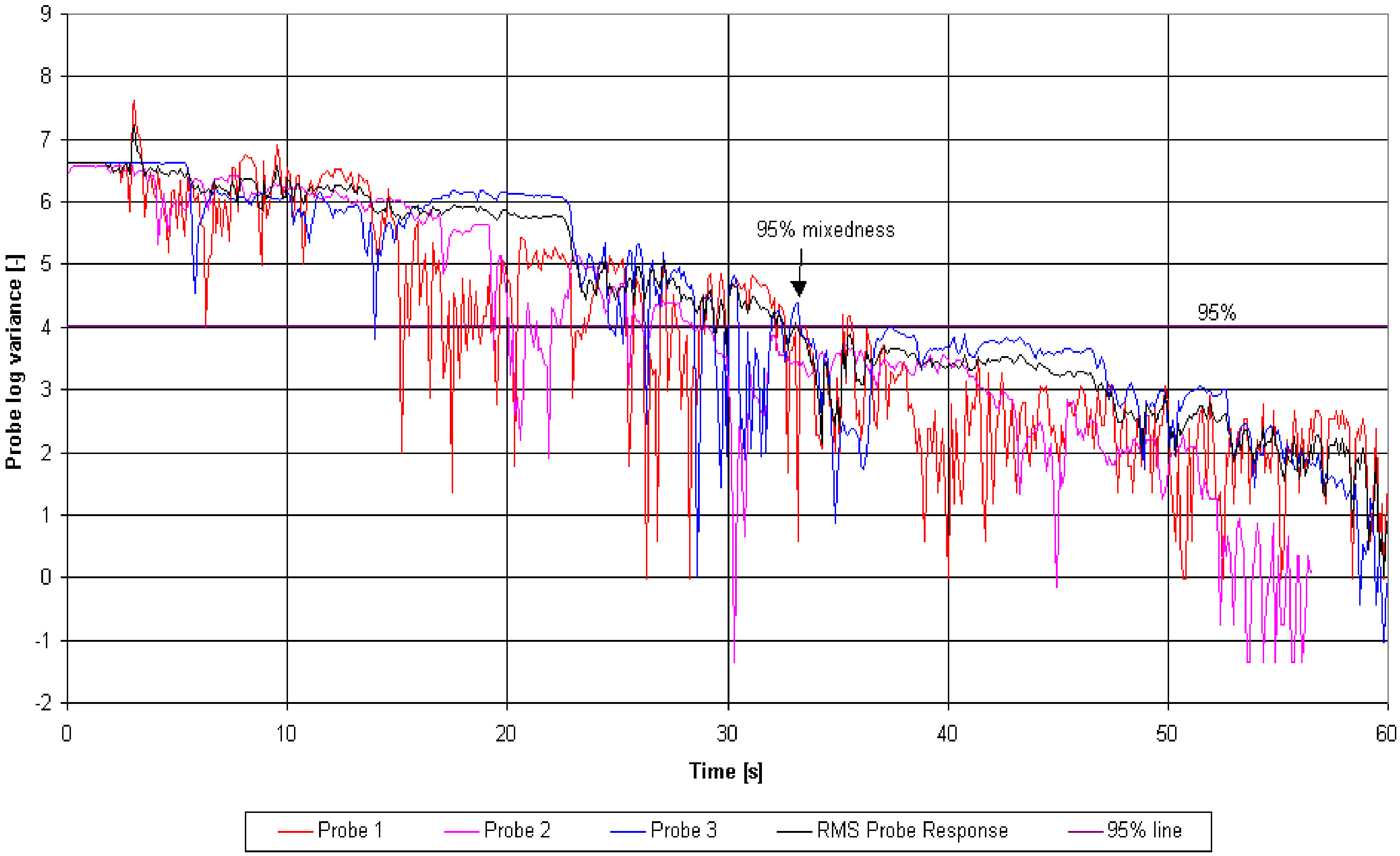


Use normalized probe output:

$C'_i=(C_i-C_0)/(C_{inf}-C_0)$

Figure 4-16 (from <u>Handbook of Industrial Mixing</u>, p.173)

Optimizing Mix Performance



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

Fig. 4-17 (from CD accompanying <u>Handbook of Mixing</u>)

Optimizing Mix Performance

- For 95% mixing time, C' = 0.95

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

$= -3+0.398$

$= -2.602$

Mixing time → 33 sec from Fig. 4-17

Assuming a linear relationship of mixedness

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

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

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 = $\rho Ud/u$ 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

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

  >5000 (turbulent)

Optimizing Mix Performance

Relationship of Mix Parameters

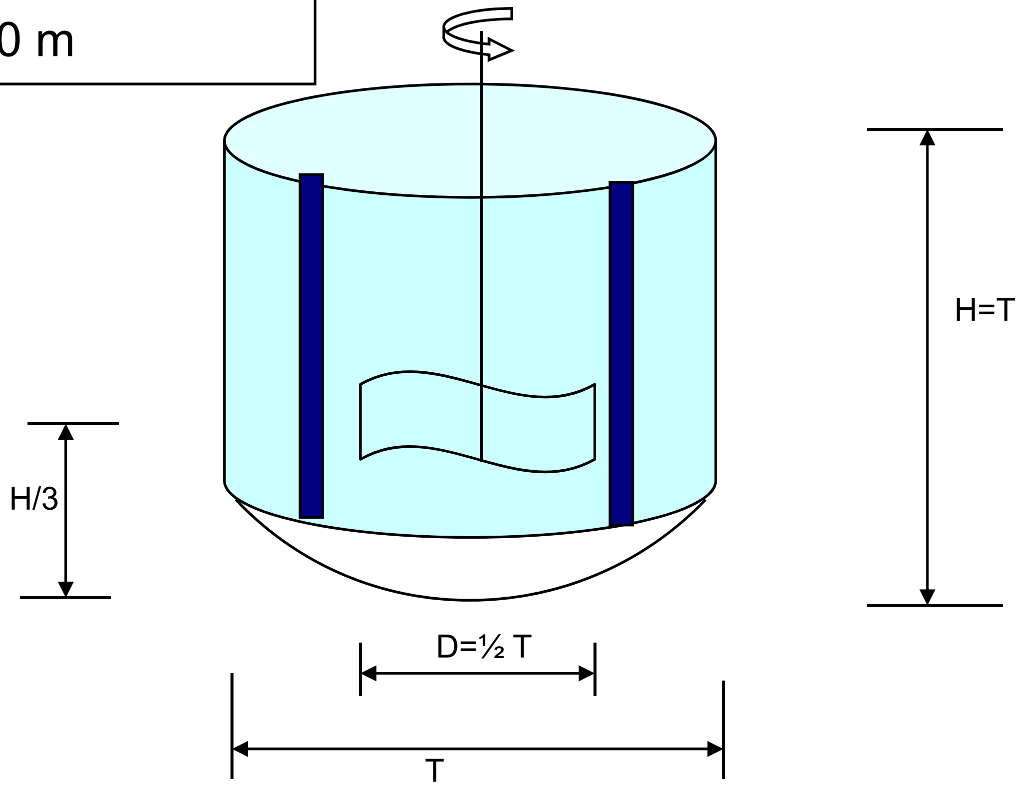
Impeller Reynolds Number

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

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

Optimizing Mix Performance

Relationship of Mix Parameters

Grenville Correlation

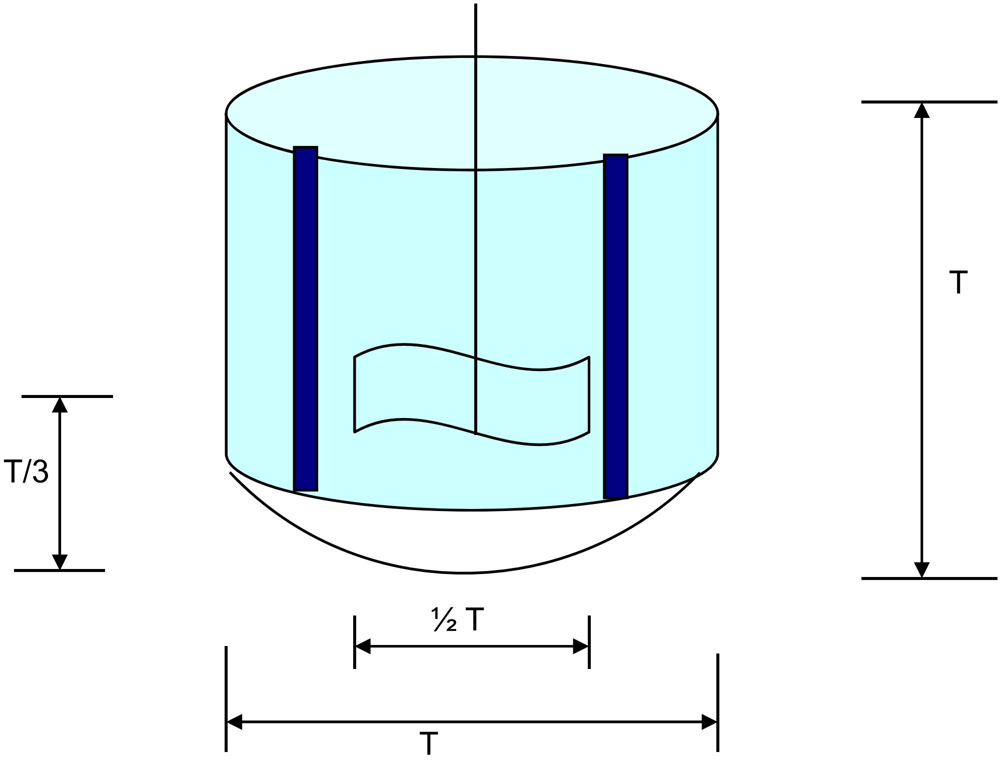
- Impeller transitional regime ($50<Re_{impeller}<5000$)
- Standard Baffles (~0.1T)
- One impeller, at 1/3 H
- $(P_o)^{2/3}N[\text{mix time}]Re(D^2/T^2) = 33{,}489$

  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, $5.2 \longrightarrow 6.8$, 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)

Optimizing Mix Performance

Overall Conclusions

- Optimal mixing is a vital part of coating operations
- In this paper, measurement techniques to characterize an existing tank and agitator have been discussed.
- A general view of the relationship of mix parameters has been shown.
- Finally, a calculation method to evaluate a new fluid in an existing tank has been demonstrated.
- Balancing batch sheet mix times with calculated or measured mix times is left to the reader.

Optimizing Mix Performance

Thank You