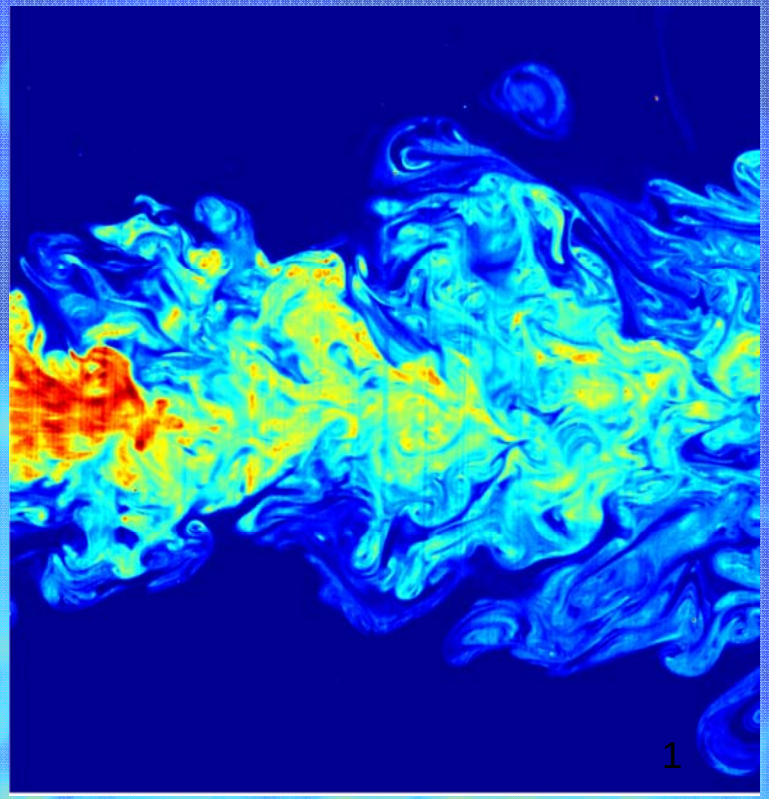
What does well mixed mean?

Prof. Suzanne Kresta, University of Alberta
AIChE Student Conference
San Francisco, November 2, 2013



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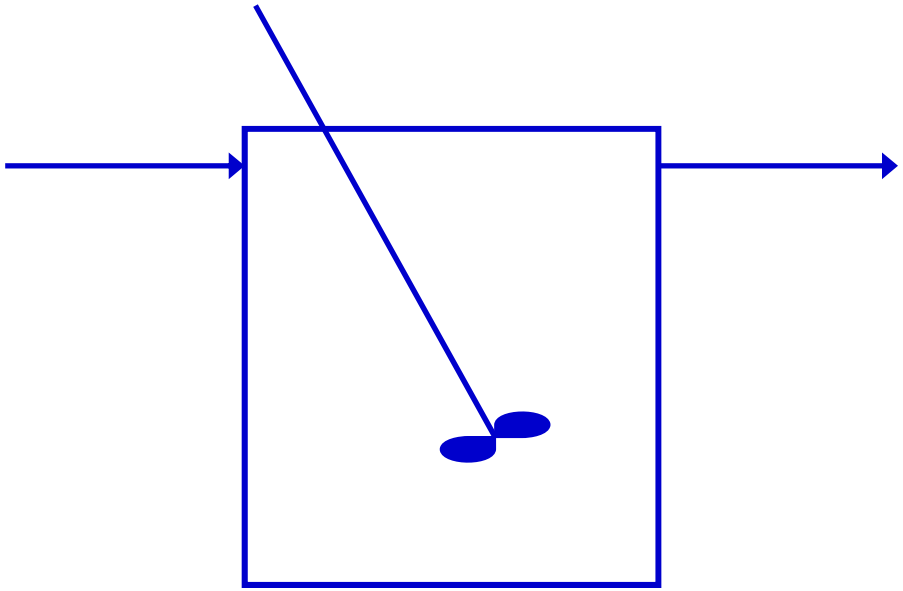
“What do you mean by Well Mixed?”



This is a well mixed CSTR.

This is a coffee mug.

Well mixed is not a clear definition, and perfectly mixed in a very short time is only a safe assumption for perfectly miscible low viscosity fluids.

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Islands of unmixedness

important for pharmaceuticals, fine chemicals, cosmetics, food, all made in small batches

Macro-scale mixing, and segregation of **concentration**

t = 0s **t = 30 s** **t = 2 min** **t = 5 min**

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Other examples?

- What other examples can you give of a mixing problem from every day life *(not always the kitchen!) With the person next to you, come up with 5 in 2 minutes!*
- Where else could mixing cause a problem in your design projects, or other technical experiences? *(notice this as we go forward through the industrial examples)*

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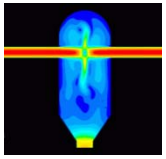
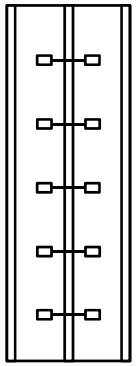
Micro- to Mega-scale



CIJR
4 mm,
1 mL



CIST
120 mm,
1 L

- When scaling down to a micro-L vessel and nano-sized particles, particle mass becomes insignificant relative to surface forces (nano-technology)
- When scaling up to the ML scale, the bulk blend time becomes infinitely long and local mixing conditions dominate (mixing technology)

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Industrial Mixing

- Blending
- Multiphase Mixing
  - Just contacted (macro-)
  - Uniform Distribution (meso-)
  - Size Reduction (meso- and micro-)
- Mixing Sensitive Reactions
  - Heterogeneous (multiphase)
  - Homogeneous

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Example 1: Turbulent blending

Well mixed = uniform concentration

Mixing happens in many geometries besides stirred tanks!

Design for uniform concentration

Specify the number of static mixer elements needed

This can be harder than it looks!

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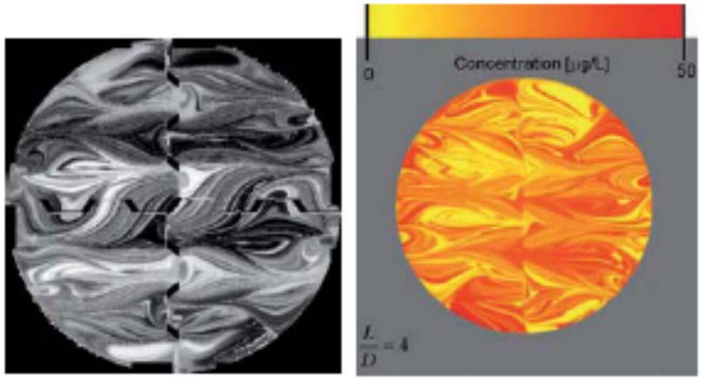
Example 2: Laminar blending

Well mixed = no visible defects at the 20μm scale



In this case the key specification is the striation thickness.

Design for scale reduction

Specify the number of static mixer elements needed

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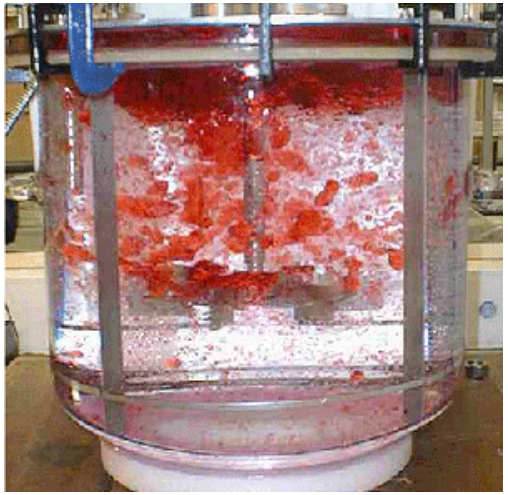
Example 3: Multiphase Mixing

Well mixed = Just Dispersed

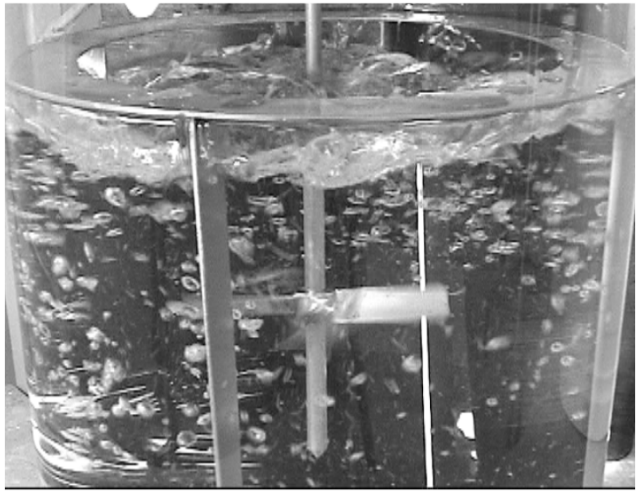
Dispersed phase must not be clustered together

Specify impeller speed, Njs, Njd

Key objective is to incorporate the second phase



liquid draw down



air entrainment
and solids suspension

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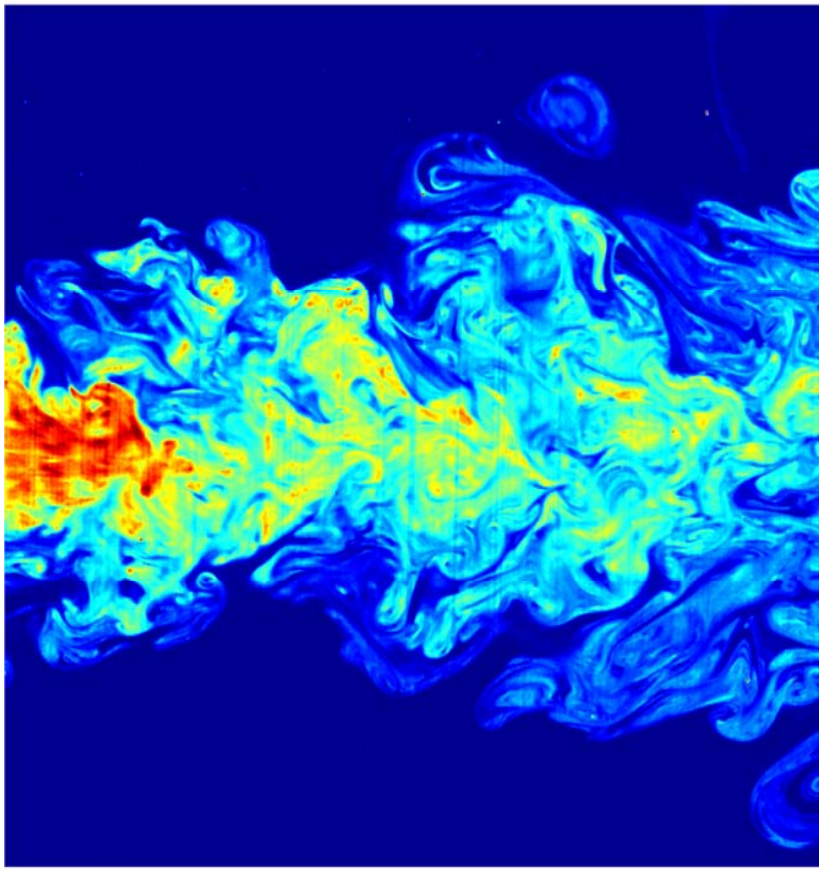
Example 4: Mixing in a feed jet



What matters most?

Plume dispersion?

Eddy size?

Mixing time and length?

The key variable depends on the application.

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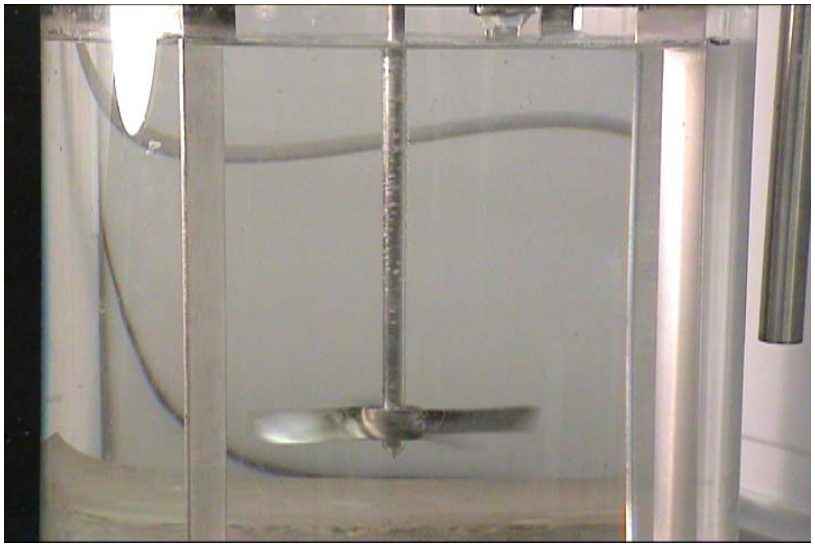
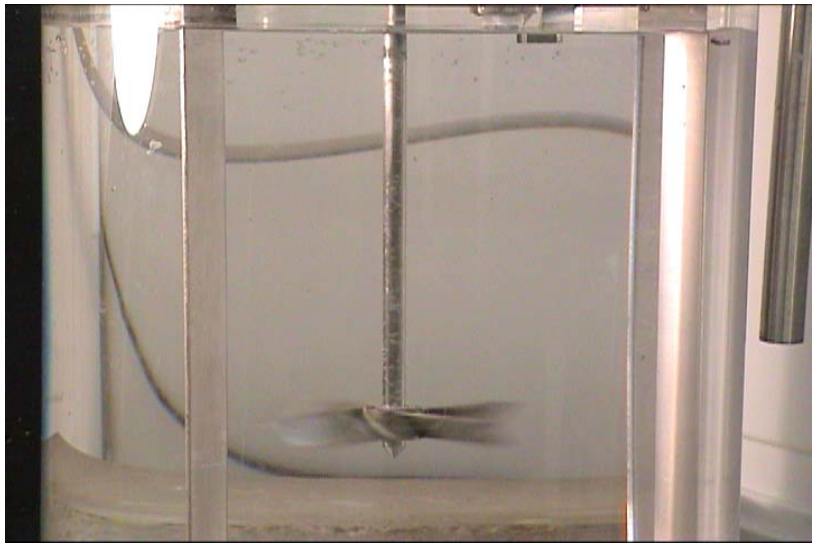
Segregated feed plume

Feed Time = 901 seconds



Feed Time = 21 s



Local concentration and *local* mixing rates determine the outcome of the reaction.

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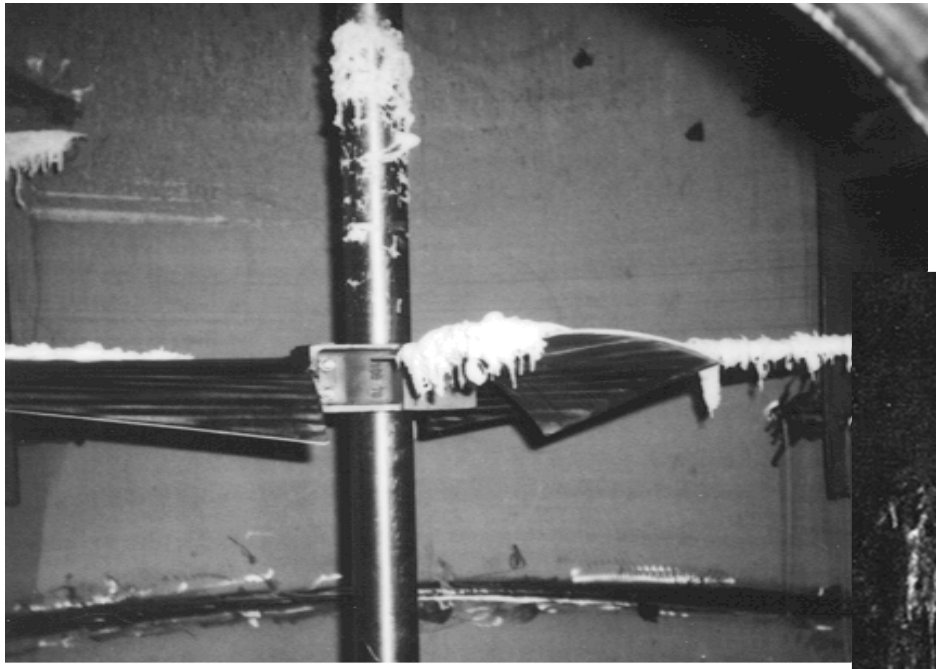
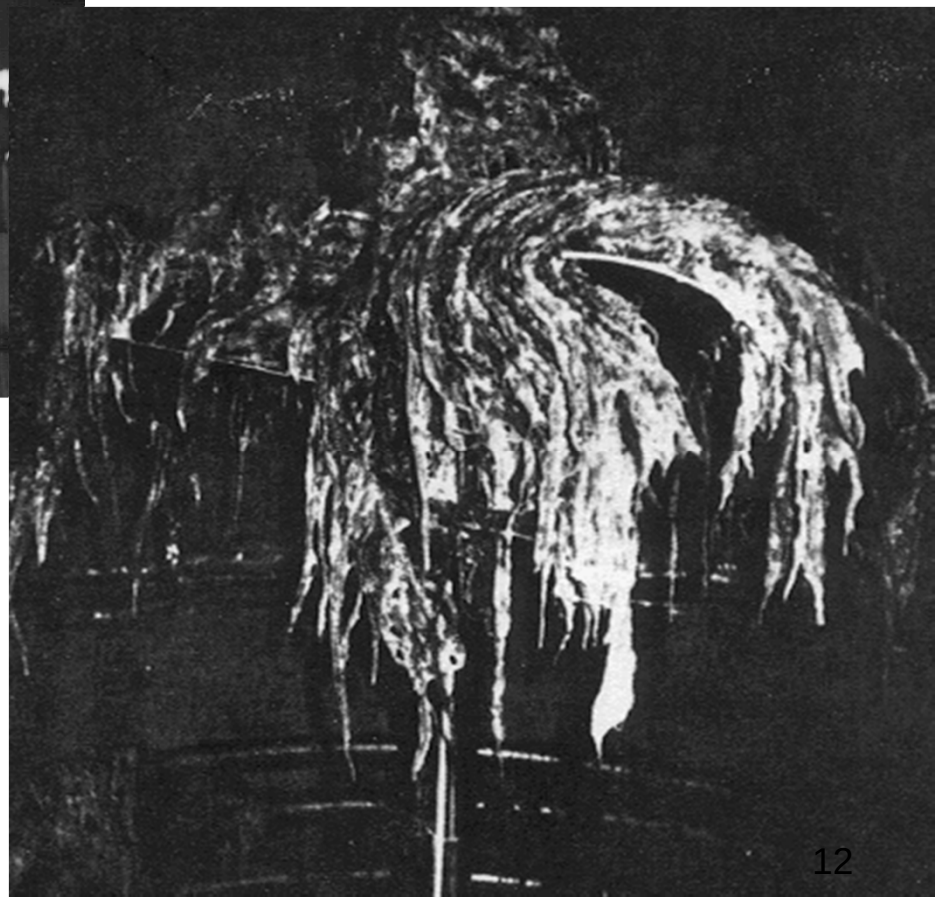
Feed at the impeller

(rapid drop in concentration)



Feed at the surface

(high local concentration persists longer)



Meso-scale segregation in concentration leads to an undesired side reaction.

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Other examples?

- Where else could mixing cause a problem in your design projects, or other technical experiences?
- Does this definition include your problem?

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Technical Definition of Mixing

Mixing has three physical dimensions (concentration, scale, and rate)

It requires three design specifications:

- *Uniformity of concentration*
- *A specified scale of segregation*
- *A required rate of mixing, or mixing time, which is often in competition with other rates.*

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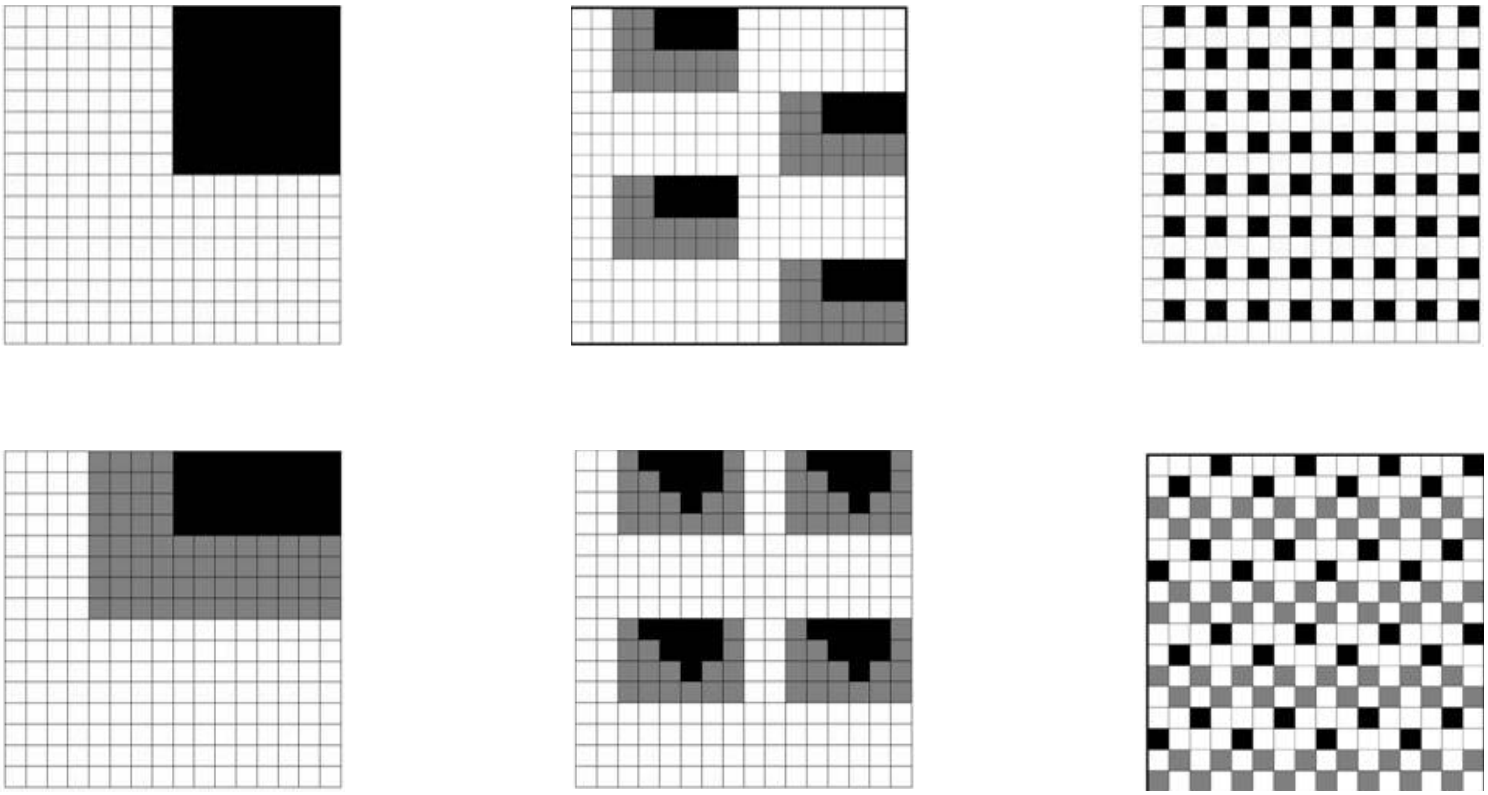
Which one is the most homogeneous?



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Measuring uniformity using CoV*

- Uniformity in concentration is measured using the standard deviation, or coefficient of variation (CoV)
- Once the CoV drops below 5% of its initial value, ($CoV/CoV_o<0.05$) blending is considered complete
- At any point in time, the equation is:

$$CoV = \frac{\sigma}{C_{mean}} = \frac{1}{C_{mean}}\sqrt{\frac{\sum (C_i - C_{mean})^2}{N}}$$

C_i = concentration at point i

C_{mean} = average concentration

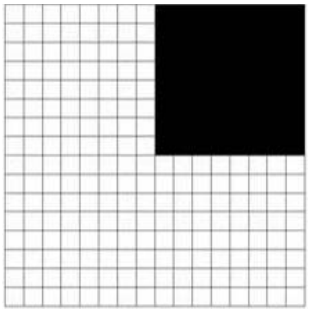
N = number of points

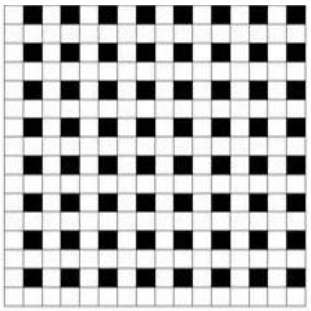
σ = sample standard deviation

Apply this to the checkerboard.

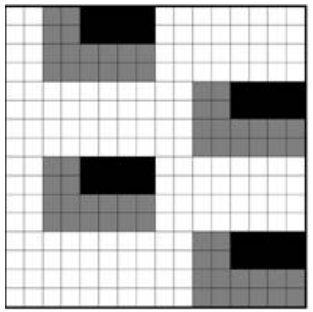
***Chapter 3 by Brown et al in Paul et al., 2004, *Handbook of Industrial Mixing,* Wiley, New York.**

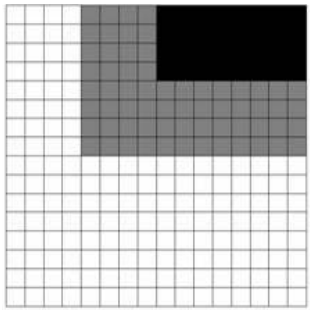
Which one has the smallest CoV?

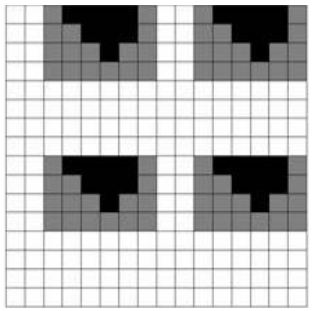


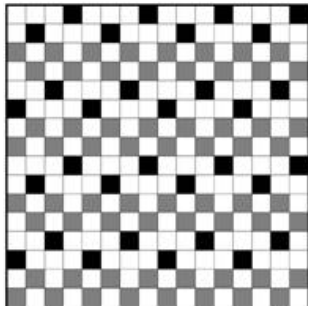


CoV= 1.73









CoV= 1.41

CoV only measures the concentration variance or the intensity of segregation – not the arrangement of areas.

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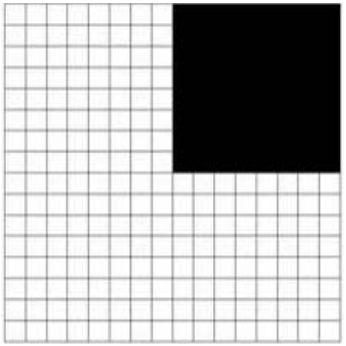
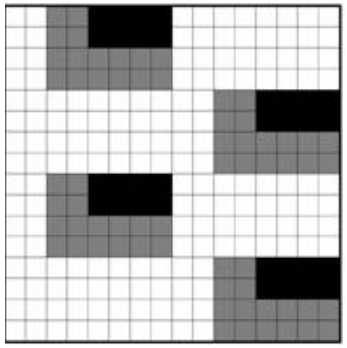
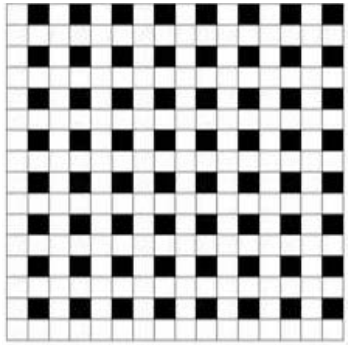
Which one has the smallest scales of segregation?



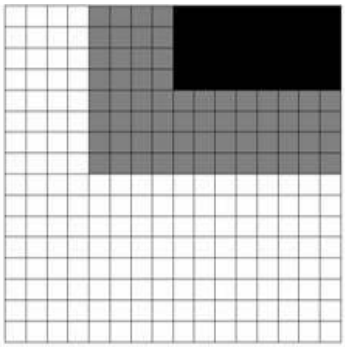
Scales: 8
Minimum = 8



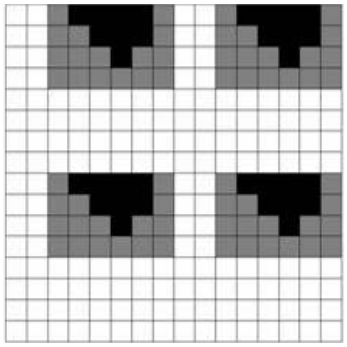
Scales: 2,4,6
Minimum = 2



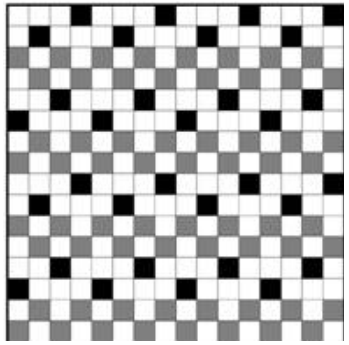
Scales: 1
Minimum = 1



Scales: 4,8,12
Minimum = 4



Scales: 1,2,4,6
Minimum = 1



Scales: 1
Minimum = 1

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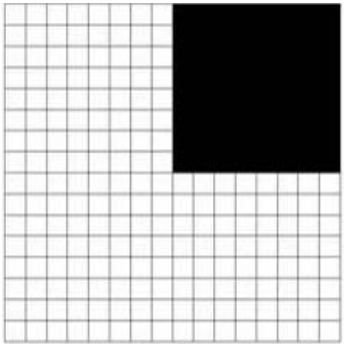
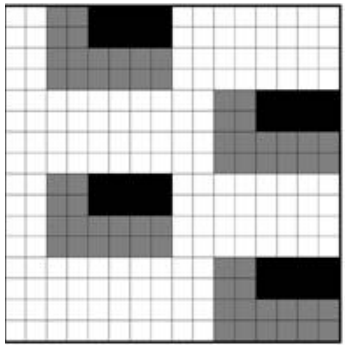
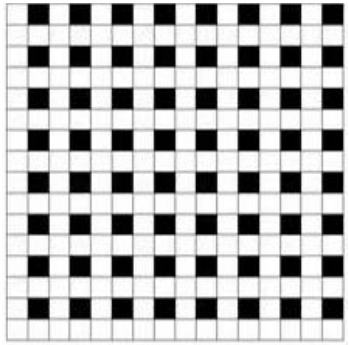
Checkerboard summary:
Scale and intensity of segregation are independent.



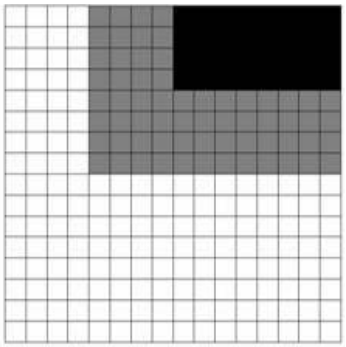
Scale: 8
CoV=1.73



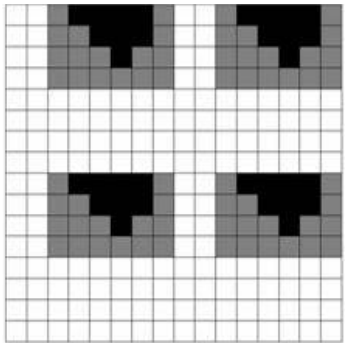
Scale: 2
CoV=1.41



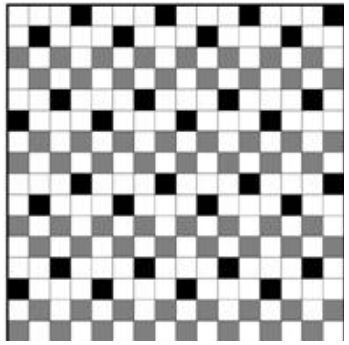
Scale: 1
CoV=1.73



Scale: 4
CoV=1.41



Scale: 1
CoV=1.41



Scale: 1
CoV=1.41

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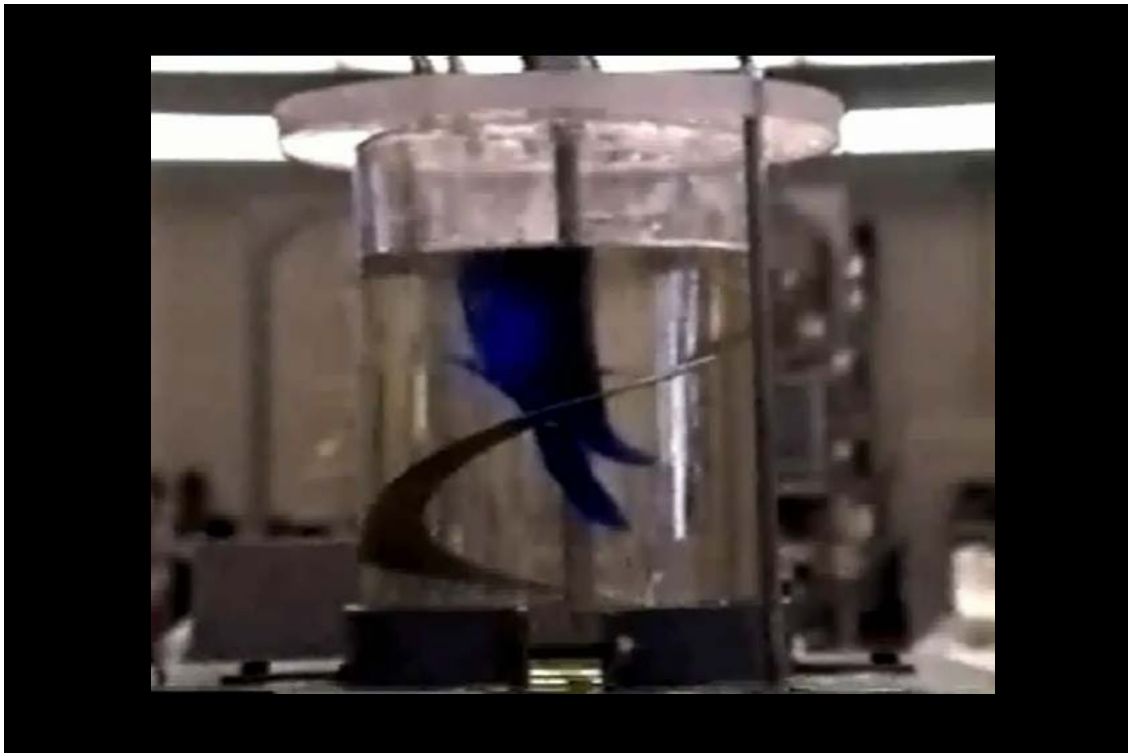
How long does it take to get to well mixed?



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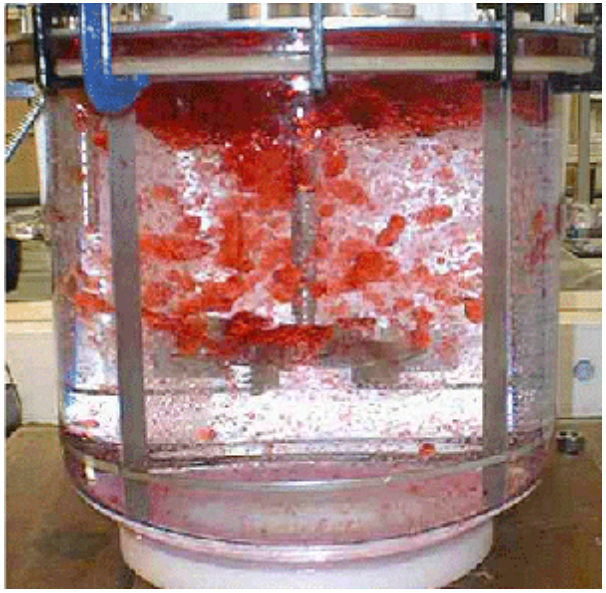
How long does it take to completely break-up drops?

In emulsion formation, the equilibrium time is the time required to get to the final drop size. It is a *meso-scale* phenomenon, occurring at scales smaller than the tank diameter or pipe size, but larger than the diffusional scales.

Other meso-scale reduction or growth rates apply for other processes.



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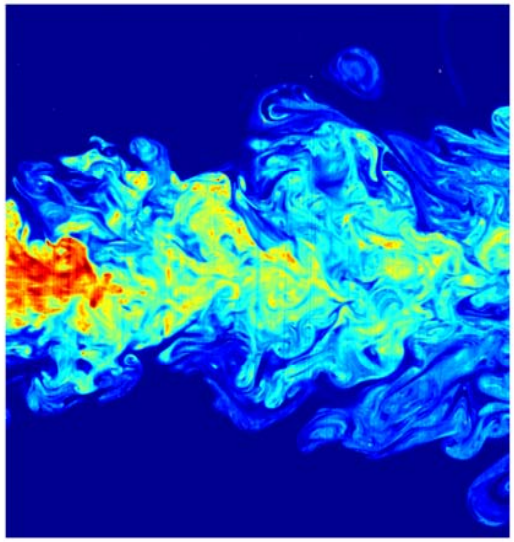
How fast do we have to mix the feed for mixing sensitive reactions?

Well mixed = outrun byproduct formation



Reaction time?

Local concentration

Turbulent mixing time?

Eddy time scale, dissipation

The key variable is the relative rates of mixing and reaction, especially at the micro-scales where diffusion and reaction become dominant.

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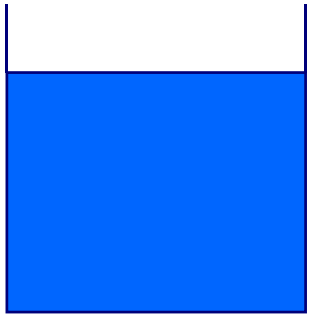
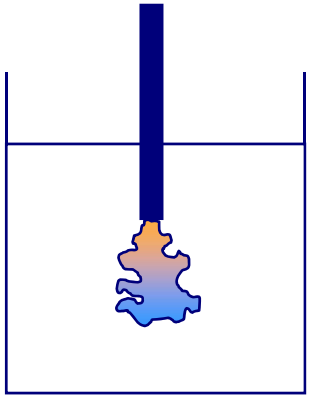
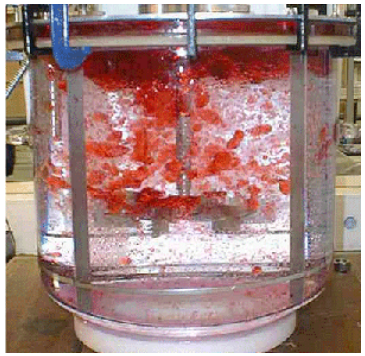
Matching mixing scale and rate is the key



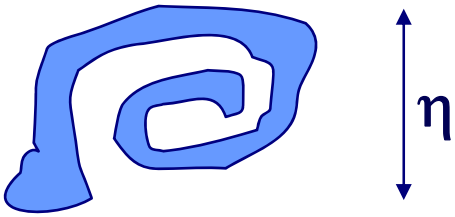
Macro-mixing:
-scale of the tank
-blend time



Meso-mixing:
-scale of the feed zone
-only have a threshold



Multi-phase mixing:
-dispersion
-mass transfer rate
-phase distribution



Micro-mixing:
-smallest scales of turbulence
-equal to striation diffusion time
-limiting time scale for many competing rate processes

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Quantitative Measures of Mixing

- *CoV (or normalized standard deviation) measures uniformity in concentration*
- *The scale of segregation comes in various forms of length scales and/or size distributions*
- *There are several mixing rates which depend on the scale of mixing:*
  - Blend time at the scale of the tank
  - Scale reduction time at the meso-scale (achieve equilibrium size)
  - Micro-mixing time at the smallest scales (limited by physical properties and turbulence or chaos)

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To Learn More

-Characterization of Impellers

Richard Grenville, Philadelphia Mixing Solutions

Yosemite A/B at 1pm and at 2pm

- Is this stuff a liquid or a solid?

Clara Gomez, Coanda

Golden Gate 4/5 at 1pm and at 2:30 pm

-me again! – here at 2:30

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…and still more!

-Mixing sessions Monday, Tuesday, Wednesday, Hilton Union Square 18

-The Handbook of Industrial Mixing

-Contact NAMF through

www.mixing.net

-or me, Dr. Suzanne Kresta, at kresta@ualberta.ca

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