Mixing History
1940 to 1965

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This paper briefly outlines the history of "mixing" from 1940 to 1965. The first decade was dominated by World War II and the subsequent recovery. There were few academic publications, and practitioners remained confused regarding units and correlations for agitator power in stirred tanks until about 1950. The next 15 years, 1950 to 1965, witnessed the birth of chemical engineering science where transport phenomena replaced unit operations and a science of mixing emerged

A 1944 Paper

A Mass Velocity Theory for Liquid Agitation

F. D. Miller and J. H. Rushton

Mixing Equipment Company

Rochester, NY

Rushton's "Kinetic Energy"

$$KE = MV^2 / 2g$$

$$KE = q\rho V^2 / 2g$$

$$\therefore KE = A\rho V^3 / 2g$$

where

M = mass

V = velocity

q = volume per unit time

A = cross-sectional area of stream

g = gravitational constant

The units are screwed up. The equation is really for power, not kinetic energy

$$P_I = A\rho V^3 / 2g$$

but $A \propto D_I^2$ and $V \propto N_I D_I$

Substitute and rearrange to get

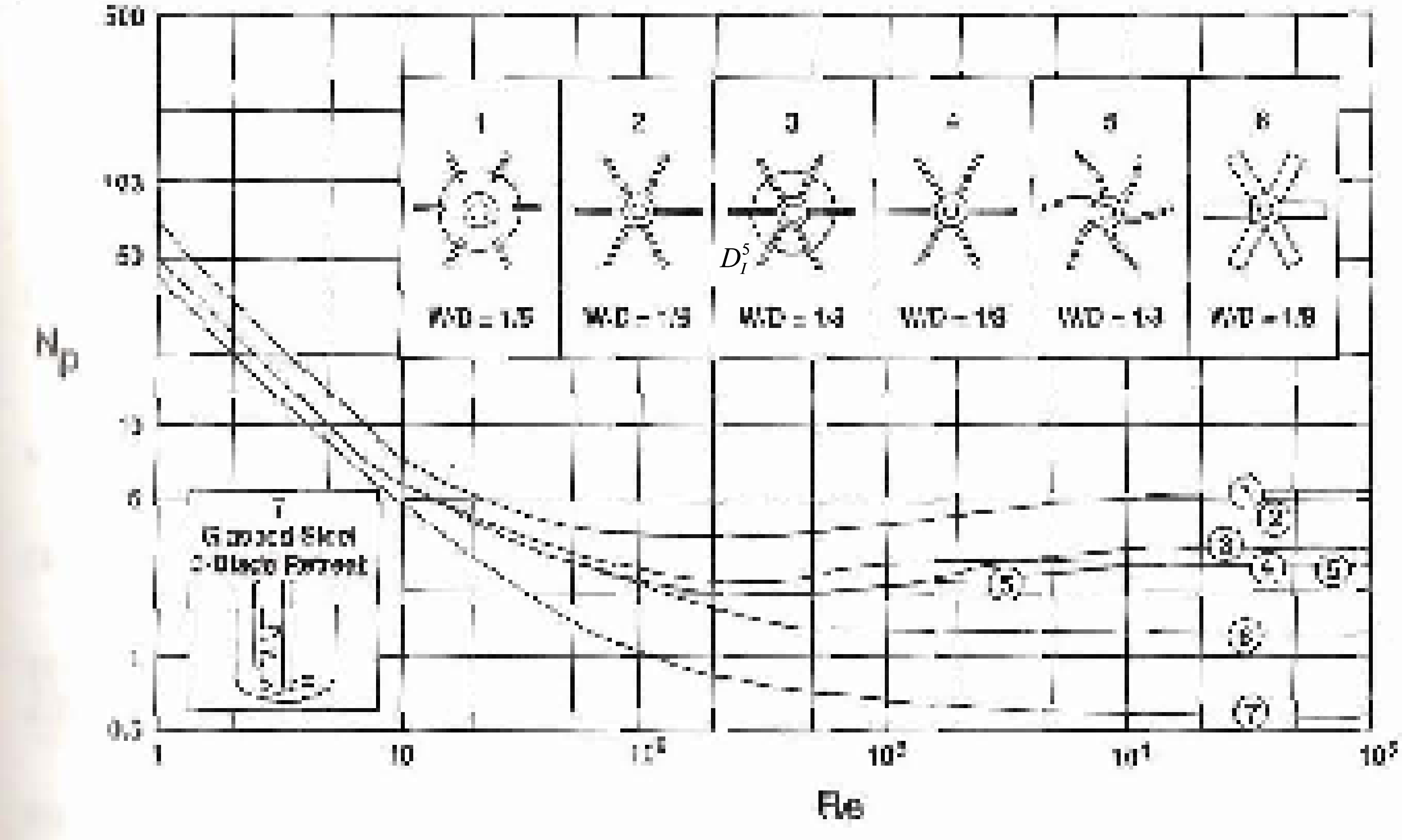
$$\frac{P_I}{\rho D_I^5 N_I^3} = \text{ constant } = \mathbf{Np}$$

Rushton's "mass velocity theory" gives the power number, but the paper just plots RPM versus HP with different lines for different prop diameters and no data points.

Six years later: Rushton, Costich and Everett, 1950

The D^5 dependence is now recognized and the original publication shows actual data points. The units remain questionable due to apparent confusion between g and g_c.

D_I^5



Through and beyond 1965, Rushton and Oldshue dominated the vendor mixing community

- They wrote the annual reviews in I&EC
- Jim began his international outreach

Norwood and Metzner measured mixing times, 1960.

Two key book were being written, but didn’t emerge until 1966:

Holland and Chapman

Uhl and Gray

The academic community began an intellectual revolution in 1952 Here are some key players:

Danckwerts, 1952 - 1958

Cleland and Wilhelm, 1956

Mohr, Saxton, and Jepson, 1957

Levenspiel, Smith, and Bischoff, 1957 - 1962

Zwietering, 1959

Bird, Stewart and Lightfoot, 1960

The revolution:

Transport phenomena replaced unit ops

Distributed system models replaced lumped models

1952 Danckwerts starts *Chemical Engineering Science*

1960 BS&L publish *Transport Phenomena*

Danckwert's contributions to mixing

Provided quantitative measures of the extent of mixing

Defined residence time distributions in flow systems

Rediscovered the axial dispersion model and its boundary conditions

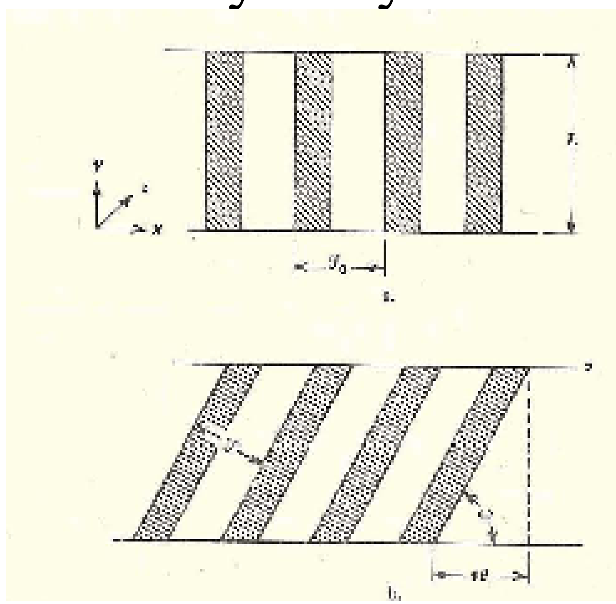
Introduced concepts of segregation and micromixing

Cleland and Wilhelm’s contributions to mixing

Provided the first numerical solution to a two-dimensional convective diffusion equation, thereby providing the groundwork for CFD

Mohr, Saxton, and Jepson's contributions to mixing

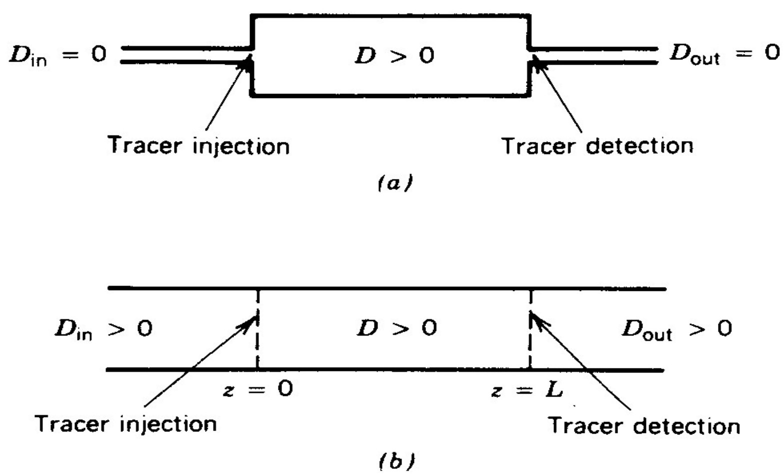
Introduced the concept of striation thickness and showed how it responded to hydrodynamics



Ranz and Ottino came many years later

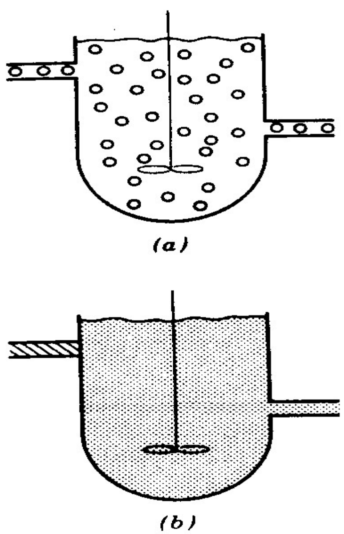
Levenspiel, Smith, and Bischoff's contributions to mixing

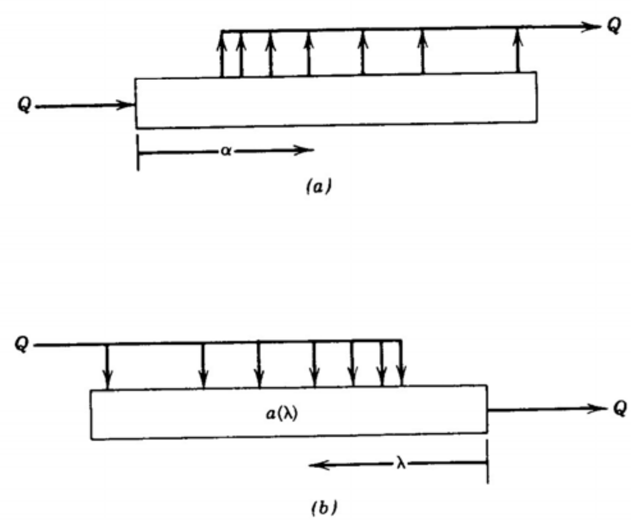
Developed measurement techniques to characterize pipeline mixing in turbulent flow



Zwietering's contributions to mixing

Quantified the concepts of segregation and micromixing





Bird, Stewart and Lightfoot's Contribution to Mixing

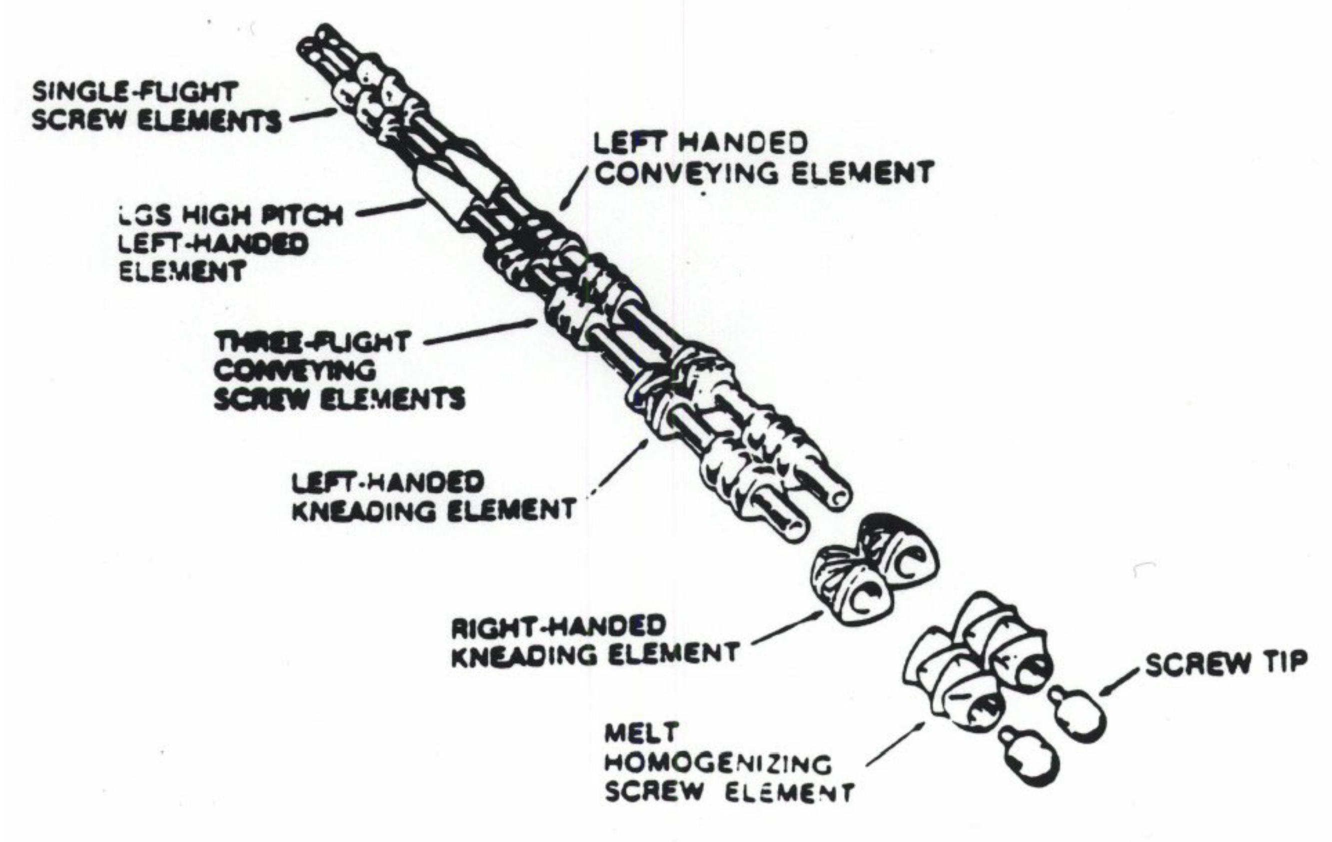
Revolutionized graduate education

Professor had to get smarter

Mixing in laminar flow systems could be rigorously defined and even solved

Empiricisms still needed for turbulence

Back to Hardware – Now for Plastics



And here is perhaps the first static mixer, circa 1950

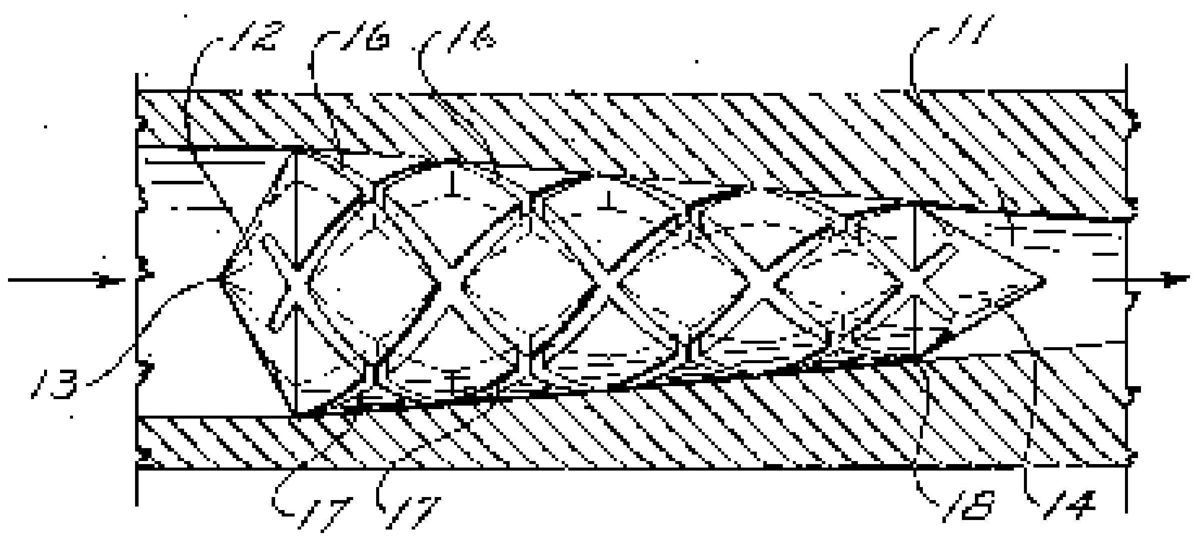


Fig 2

The Greatest Generation?

Except for Kolmogorov, the war years slowed academic research, but the period from about 1950 to 1965 produced remarkable changes in mixing science and engineering.