Mixing History
1940 to 1965

Bruce Nauman
Rensselaer Polytechnic Institute
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 Mass Velocity Theory for Liquid Agitation

F. D. Miller and J. H. Rushton
Mixing Equipment Company
Rochester, NY
Rushton’s “Kinetic Energy”

\[ KE = \frac{MV^2}{2g} \]
\[ KE = q \rho V^2 / 2g \]
\[ \therefore KE = A \rho V^3 / 2g \]

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

\[ \frac{P_I}{\rho D_I^5 N_I^3} = \text{constant} = Np \]

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 $g_c$. 

![Diagram with axes, data points, and symbols related to $D^5$ and $g_c$.]
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

![Diagram](a)

![Diagram](b)
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
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.