Process Intensification Network NL - Spring Session
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Process Intensification Using Rotor-Stator Devices: Challenges, Opportunities and Advances

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Design strategy

- Design strategy based on mechanistic understanding of how materials & process interactions affect product performance
- Product quality & performance ensured by design & operation of effective & efficient processes
- Flawless execution:
  - Accelerate time to market
  - Less trial and error
  - Improve efficiency
  - Successful companies deliver innovative products first and profitably
Applications & Benefits

- Rotor-stator mixers are widely used in process industries to manufacture:
  - Foods, personal care, pharmaceuticals, fine chemicals
  - Structured liquid-liquid and solid-liquid products
- Provide a focused delivery of energy and shear in processes:
  - Emulsification, de-agglomeration, mixing, dissolution
- Central to manufacturing emulsion-based products
- Advantages:
  - Flexible/versatile
  - Simple design & robust
  - Combine process stages
Characteristics & Operation

- Characteristics:
  - Close proximity of the rotor to stator – 0.1 - 1 mm
  - Tip speed – up to 40 m/s
  - Energy dissipation rates – up to $10^6$ W/kg

- Range of interchangeable work heads available:

- Batch or in-line operation
  - Poor bulk mixing in batch vessels
  - Batch requires large motors at large scale
In-line rotor-stator mixers


- Single pass reduces energy consumption and manufacturing timescales
- For multiple passes, rotor speed, flow rate and number of passes control product quality
However, “The current understanding of rotor-stator devices has almost no fundamental basis. There are few theories by which to predict, or systematic experimental protocols by which to assess, the performance of these mixers.”

Atiemo-Obeng & Calabrese, (2004), Handbook of Industrial Mixing, Chapter 8.
Context & Objectives

- Experiments are difficult and expensive
- CFD for complex geometry/multiphase systems challenging and time consuming
- Recommendations frequently based on manufacturers experience

**Aims:**

- Investigate the effect of processing conditions on power draw
- Establish scale-up rules, to maintain and control the quality and structure of multiphase products at different scales
Power draw measurements

- 150/250 Silverson mixer
- Mains water at ambient temperature
- Flow rate measured by mass flow meter and controlled by a valve downstream of the mixer
- Rotor speed controlled by frequency inverter
  - Up to 12,000 rpm
- DeltaV control system measures
  - Temperatures, flow rate, pressures, torque etc.
Power draw measurements

Method 1 – Calorimetry:

\[ P = M C_p \Delta T \]

- Calorimetry – more accurate at low flow rates
- Both methods require corrections for calibration
- Calorimetry requires lagging and steady state conditions
- Accounting for power due to friction in bearings is essential

Method 2 – Torque:

\[ P = 2 \pi N T \]

- Torque – more accurate at high flow rates

Calorimetry – more accurate at low flow rates

Torque meter

Temperature probes
Power draw results

- Rotor speed and flow rate affect power draw
- Conventional approach does not work

\[ P_o = \frac{P}{\rho N^3 D^5} \]

Power draw expression

- Turbulent power draw for an in-line rotor-stator mixer [2]:

\[ P = P_{o} \rho N^{3} D^{5} + k_{1} M N^{2} D^{2} + P_{L} \]

‘Tank’ term, \( P_{T} \)  ‘Flow’ term, \( P_{F} \)  ‘Losses’ term, \( P_{L} \)

- \( P_{L} \) negligible with careful measurement

<table>
<thead>
<tr>
<th>Method</th>
<th>Constants</th>
<th>Value</th>
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<tbody>
<tr>
<td>Calorimetry</td>
<td>( P_{o} )</td>
<td>0.229</td>
</tr>
<tr>
<td></td>
<td>( k_{1} )</td>
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<td>Torque</td>
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<td></td>
<td>( k_{1} )</td>
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Graphical method

- Power draw constants can be obtained graphically:

\[
\frac{P}{\rho N^3 D^5} = P_0 Z + \frac{k_1 M}{\rho N D^3}
\]

Dimensionless power draw

Dimensionless flow rate

\[
Po = 9.24 N_Q + 0.207 \\
R^2 = 0.987
\]

Summary

- Recent publications include: