Exploring Multi-Shafts Stirred Reactors: Investigating Turbulent Chaos and Mixing Characteristics through Experiments and Large Eddy Simulations

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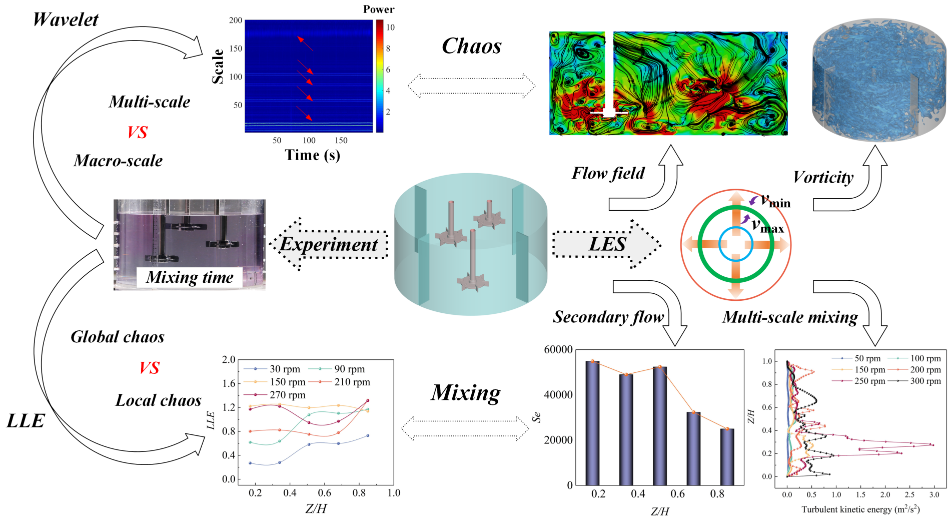
In the field of bioprocessing, achieving effective mixing of biological components is of paramount importance. However, the traditional single shaft stirred reactor, characterized by a symmetrical flow field, poses an energy consumption challenge. The utilization of a multi-shaft stirred reactor presents an innovative solution for optimizing the distribution of flow field energy, thereby improving turbulent chaos and mixing performance. This study conducted experiments and Large Eddy Simulations (LES) on three different stirred reactors, comprehensively analyzing key indicators such as mixing time, Largest Lyapunov Exponent (LLE), wavelet analysis, simulated flow field visualization, swirl number, and secondary flow intensity. The research findings highlight that the Triple-shafts Three-impellers Reactor (T-T-STR) features a flow field rich in multi-scale vortices, leading to a significant reduction in mixing times. However, a critical observation emerged at a rotational speed of approximately 200 rpm, indicating a sudden deterioration in the mixing performance of the T-T-STR, as confirmed by the LLE. This suggests that, under a uniform flow structure, local chaotic characteristics alone are sufficient to reflect overall changes in turbulent chaos and mixing performance. The decline in mixing performance is attributed to the degradation of the energy cascade effect, evident through discernible variations in mixing performance at different scales. Additionally, the T-T-STR exhibits a near-zero swirl number and heightened secondary flow intensity, indicating its superior turbulent diffusion capability arising from its unique flow field structure. In summary, during the scaling-up process of stirred reactors, strategically increasing the aspect ratio and incorporating multiple shafts emerge as effective strategies to mitigate the amplification effect. The application of such an innovative reactor configuration extends beyond conventional chemical processes, holding promise in enhancing bio-mixing efficiency and ensuring optimal conditions for biological reactions. The significance of these findings provides a promising pathway for advancements in both conventional chemical processes and the design and performance of bioreactors.



Wavelet
Multi-scale
VS
Macro-scale
Power
Scale
Time (s)
Chaos
Flow field
Vorticity
Experiment
LES
Mixing time
Secondary flow
Multi-scale mixing
Global chaos
VS
Local chaos
LLE
Mixing
Z/H
Turbulent kinetic energy (m2/s2)