NEWSLETTER

Gas–Liquid Mixing: Why Higher RPM Is Not Always Better

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Introduction

- Gas–liquid mixing plays a critical role in determining **reaction performance, mass transfer efficiency, and product quality** in a wide range of chemical and biochemical processes. Efficient gas dispersion ensures adequate **interfacial area** for mass transfer, directly influencing reaction rates, conversion levels, and overall process reliability.
- In industrial practice, it is often assumed that increasing agitator speed enhances turbulence, improves gas dispersion, and leads to better mixing performance. While higher RPM increases energy input, it does **not necessarily result in effective gas–liquid contact**. In many cases, excessive agitation can lead to undesirable hydrodynamic effects such as **vortex formation, gas entrainment, and non-uniform flow patterns, ultimately** reducing mixing efficiency.
- The performance of gas–liquid systems is governed by a complex interaction between **impeller design, reactor geometry, operating conditions, and fluid properties**. Parameters such as **gas hold-up, bubble size distribution, circulation patterns, and mass transfer coefficient (kLa)** are strongly influenced by these factors and must be evaluated together rather than relying solely on agitation speed.
- VisiMix provides an advanced simulation platform that integrates hydrodynamics, reactor configuration, and operating conditions into a single predictive framework. By accurately capturing real mixing behavior, VisiMix enables engineers to **evaluate gas distribution, identify optimal operating windows, and make informed scale-up decisions** while minimizing experimental trials.

Objective

This study aimed to investigate the lack of reaction progression observed in the **25 L reactor at 960 RPM,** despite high agitation intensity, in comparison with the **5 L reactor,** where the reaction performed satisfactorily.

The study aimed to:

- Correlate mixing performance and reaction behavior across different reactor capacities.
- Identify the hydrodynamic reasons for poor gas–liquid interaction at higher agitation speeds.
- Evaluate the performance of the **250 L reactor based on batch execution data.**
- Assess the suitability of the **750 L (baffled)** reactors for reliable scale-up.
- Minimize experimental trials and reduce consumption of high-value materials through a simulation-driven approach using VisiMix.

Physical Observations

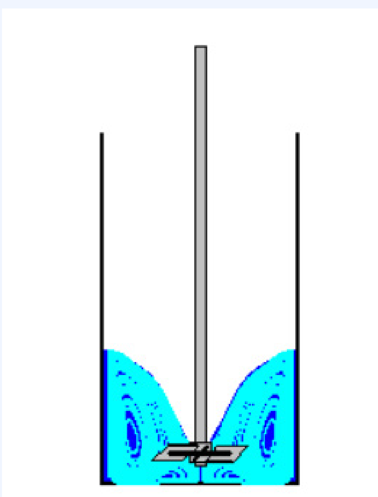
- In the **5 L reactor,** the reaction proceeded smoothly with satisfactory mixing performance.
- In the **25 L reactor at 960 RPM,** no effective gas distribution was observed across different working volumes, indicating poor gas–liquid interaction despite high energy input.
- At different working volumes and reduced agitation speeds:
  - **8 L at 500 RPM** → satisfactory gas distribution observed.
  - **10 L at 700 RPM** → satisfactory gas distribution observed.
- In the **250 L reactor, t**he reaction did not reach completion even after 76 hours of operation. Increasing the oxygen pressure from 2 kg/cm^2 to 3 kg/cm^2 did not result in any observable improvement in reaction progress.

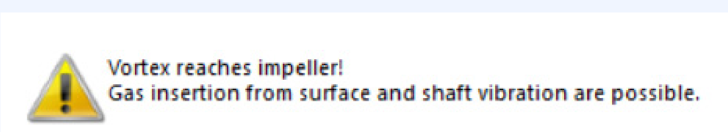
- The **750 L reactor (with baffles)** was considered for scale-up assessment.
- The observations were compared with the 5 L reactor to assess consistency in mixing performance across different reactor capacities.

VisiMix Analysis

VisiMix simulations were carried out to understand the hydrodynamic behavior responsible for the observed differences in gas–liquid mixing performance across reactor scales and operating conditions. The analysis focused on evaluating flow patterns, gas distribution, and circulation characteristics under varying agitation speeds.

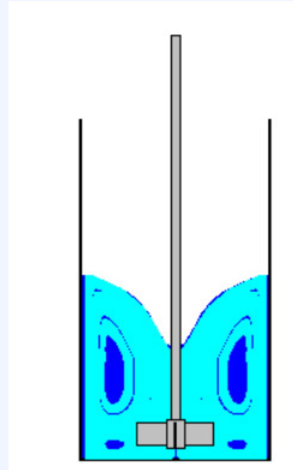
25 L reactor at 960 RPM





The image shows pronounced vortex formation extending from the liquid surface down to the impeller region in the 25 L reactor at 960 RPM.
The flow is concentrated near the impeller with non-uniform circulation in the bulk liquid, indicating ineffective gas–liquid mixing.

5 L reactor



In comparison, the 5 L reactor exhibits a stable flow pattern with only minor vortex formation, which does not extend to the impeller region.
Uniform circulation is maintained throughout the reactor, enabling effective gas–liquid interaction.

The comparison clearly shows that vortex formation extending to the impeller region adversely affects mixing performance.
Effective gas–liquid interaction is achieved only when stable circulation is maintained without excessive vortex formation.
At high agitation speeds, excessive turbulence drives gas bubbles rapidly toward the liquid surface, reducing gas residence time. As a result, gas escapes before sufficient contact time is achieved for mass transfer. This leads to reduced gas–liquid interaction and lower reaction conversion, despite higher energy input.

Summary of Simulation Results

The simulations were carried out by incorporating detailed inputs, including reactor geometry, baffle configuration, impeller design, fluid properties, and gas flow rate. Based on these inputs, VisiMix predicts the hydrodynamic behavior and gas–liquid mixing performance under different operating conditions.

Table: Summary of gas–liquid mixing performance across different reactor scales

PARAMETER	Units	5 L	5 L	25 L	25 L	25 L	25 L	25 L	25 L	250 L	750 L	750 L
Reaction mass volume	L	2.5 L	1.3 L	6.25 L	13 L	8 L	8 L	8 L	10 L	30 L	270 L	270 L
RPM		700	700	960	960	960	800	500	700	110	210	155
Energy dissipation in the bulk volume	W/kg	1.43	1.92	21.9	16.1	21.4	12.4	2.2	7.22	0.0989	1.94	0.784
Microscale of turbulence in the bulk of volume	m	2.89E-05	2.69E-05	1.46E-05	1.58E-05	1.47E-05	1.69E-05	2.60E-05	1.93E-05	5.64E-05	2.68E-05	3.36E-05
Characteristic time of micro-mixing	s	0.836	0.722	0.214	0.249	0.216	0.284	0.674	0.372	3.18	0.716	1.13
Mixing power	W	10.1	6.34	245	415	318	184	32.8	138	7.22	1320	533
GAS-LIQUID MIXING												
Check distribution		Satisfactory	Satisfactory	No gas distribution	No gas distribution	No gas distribution	Satisfactory	Satisfactory	Satisfactory	No gas distribution	Satisfactory	Satisfactory
Gas hold-up		0.019	0.0245				0.253	0.0814	0.259		0.219	0.0478
Sauter mean bubble diameter	m	0.00237	0.00221				0.00231	0.0024	0.00287		0.00387	0.00295
Specific mass transfer area	m^2/m^3	48.1	66.3				657	204	542		339	97.2
Specific mass trasnfer coefficient	1/s	**0.0394**	**0.0581**				**0.947**	**0.199**	**0.679**		**0.315**	**0.0758**

The results clearly demonstrate that higher agitation intensity does not ensure improved gas–liquid mixing, with poor gas distribution observed at high RPM in the 25 L reactor, while improved performance is achieved under optimized conditions.

Key Observations

25 L Reactor

- At **960 RPM,** a deep vortex extending to the impeller region is observed, leading to ineffective gas–liquid mixing.
- No significant gas distribution is achieved above **800 RPM,** despite high agitation intensity.
- This indicates that increasing RPM beyond a certain limit results in unstable flow conditions rather than improved mixing performance.

250 L Reactor

- In the **250 L unbaffled reactor**, no effective gas distribution is observed under the studied operating conditions, even after prolonged operation and increased pressure.
- This highlights the limitation of relying on operating intensity alone without addressing hydrodynamic constraints.

750 L Reactor

- In the 750 L baffled reactor, a working volume of **270 L at 210 RPM** provides mixing performance comparable to the 5 L reactor.
- Key hydrodynamic and mass transfer parameters are closely aligned, indicating that appropriate reactor configuration and operating conditions enable successful scale-up.

The results demonstrate that effective gas–liquid mixing is governed by hydrodynamics, reactor configuration, and flow stability rather than agitation speed alone. Excessive agitation can lead to vortex formation and unstable flow patterns, causing gas bubbles to escape rapidly and reducing gas residence time. As a result, mass transfer efficiency decreases, leading to poor gas dispersion and lower reaction conversion. **Under optimized operating conditions, stable circulation is maintained, enabling uniform mixing and efficient mass transfer.**

CONCLUSION

The study demonstrates that increasing agitation speed alone does not ensure effective gas–liquid mixing and can lead to unfavorable hydrodynamic conditions, such as vortex formation extending to the impeller region.

The results highlight that mixing performance is governed by flow stability, reactor configuration, and operating conditions rather than RPM alone. In particular, the presence of baffles and optimized operating parameters **are critical for** achieving uniform gas dispersion and efficient mass transfer.

VisiMix simulations provide a reliable framework to predict hydrodynamic behavior, enabling identification of optimal operating conditions and supporting effective scale-up while minimizing trial-and-error and the use of high-value materials.

This highlights the importance of evaluating mixing performance based on hydrodynamics rather than relying solely on agitation speed during process design and scale-up.