



## WHY CHOOSE ABEC

ABEC offers in-house expertise to conduct mixing and mass transfer studies as a service to our customers. This service helps customers understand the impact of modifications or design improvements on existing or proposed bioreactors and fermenters. By utilizing Computational Fluid Dynamics (CFD), ABEC partners with customers to accurately simulate reactor configurations and operating conditions. The results are validated in ABEC's mixing lab prior to projecting performance for full-scale configurations to demonstrate expected behavior and desired outcomes.

## BENEFITS

ABEC's engineering services are customizable to fit your needs and offer substantial benefits:

- Accurately scale process
- Predict technology transfer
- Optimize equipment design
- Mitigate risk

## UNIQUE FEATURES

- Customized studies tailored to fit process and client needs
- 100% in-house execution utilizing ABEC's simulation and experimental toolset
- Capability to design and manufacture equipment in-house
- Recommended next steps by ABEC's experienced technical experts

## MIXING AND MASS TRANSFER SERVICES

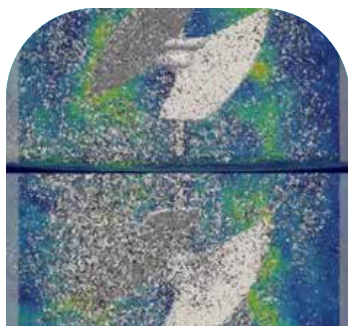
Mixing and mass transfer studies determine the impact of various elements of reactor design such as impellers, gas sparge, liquid addition point, baffles, and heat transfer surface area. ABEC's main offerings when conducting mixing and mass transfer studies include Scale-up/Scale-down, Platform Technology Transfer, System Characterization, and Equipment Design Optimization.

### SCALE-UP & SCALE-DOWN

ABEC optimizes performance at all scales ranging from process development to commercial production process equipment, ranging from milliliters to hundreds of thousands of liters. Performance and characterization studies at the process development and benchtop scale are cost-effective approaches to commercial production, as extensive lab and pilot scale testing are no longer required. ABEC ensures scalable performance by collecting data across a range of operating parameters in its customers' existing reactors and using that baseline information with its toolset to manage and project performance at the target scale.

### PLATFORM TECHNOLOGY TRANSFER

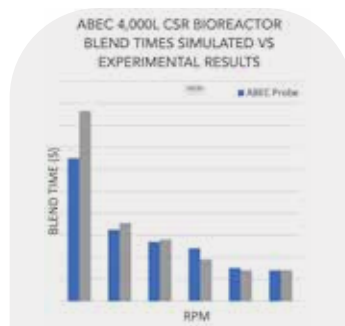
As biopharmaceutical companies continue to grow and look to move their process between different reactor configurations or platforms e.g., reusable or single-use, ABEC models the geometry and performance of existing equipment and proves the performance of a new or different existing reactor design via simulation programs or in its lab. Platform Technology Transfer is especially useful when considering one or more contract manufacturers for products carried out in different sets of equipment (e.g., different suppliers, different platforms, etc.)



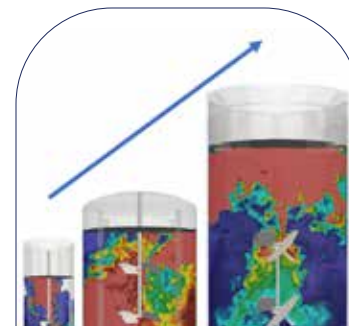
**SIMULATE  
EXPERIMENT**



**LAB  
EXPERIMENTAL  
DATA**



**VALIDATE  
SIMULATED  
RESULTS**



**SIMULATE  
SCALING**

# SERVICE BRIEF MIXING AND MASS TRANSFER SERVICES

## SYSTEM CHARACTERIZATION

ABEC can accurately characterize a system deployed at a customer's facility by gathering physical geometry from a reactor and its associated hardware (e.g., sparger, impellers, etc.) and understanding the system's operating conditions. From ABEC's analysis, a variety of performance values are calculated to understand the system's current output and overall performance.

## EQUIPMENT DESIGN OPTIMIZATION

When evaluating a customer's system for potential design updates, ABEC leverages over 45 years of experience servicing the biopharma industry. These updates include physical changes such as agitator design or impeller design, or operational improvements such as gassing rate, which generally support bioprocess improvements. By pairing customer observations and experience with ABEC's knowledge of reactor performance, we can confidently recommend hardware and operating condition changes.

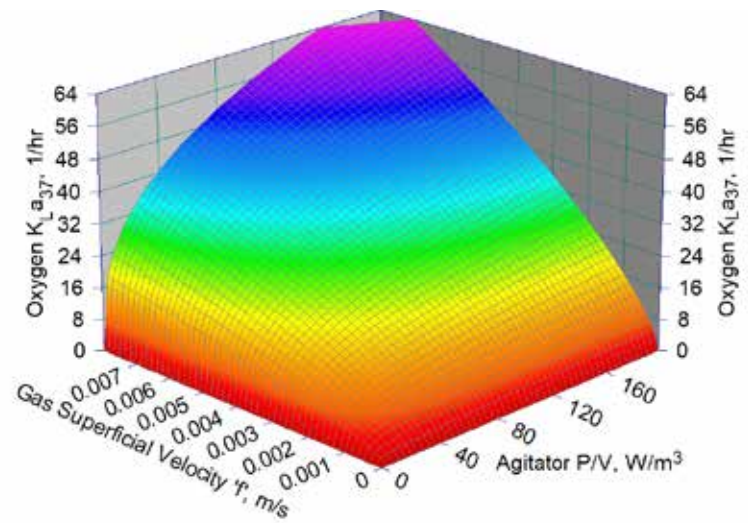
## ABEC TOOLS

The following section outlines the tools ABEC utilizes to complete the Mixing and Mass Transfer Study Services described earlier in this document.

## COMPUTATIONAL FLUID DYNAMICS

ABEC employs a physics-based model known as Lattice Boltzmann-based Computational Fluid Dynamics (LBM-CFD) to predict the performance of reactor mixing and mass transfer under different operating conditions and hardware designs. ABEC verifies the accuracy of simulation data through experimental testing, which enables ABEC to rapidly predict system performance based on physical changes or various conditions. ABEC can extend the range of simulations and demonstrate expected behavior in full-scale production reactors. ABEC's CFD modeling collects data such as:

- Blend time
- Surface vortexing
- Agitator power & impeller power numbers
- Shear and energy dissipation
- Flow fields
- Bubble size, distribution & dwell time
- Gas fluid mixing & velocity
- Mass transfer  $K_L a$  (local and overall)

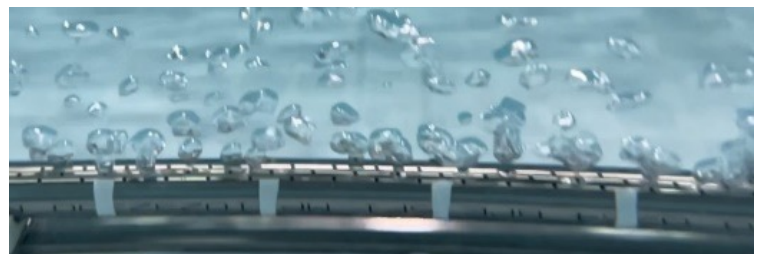


Oxygen mass transfer curve of ABEC 6,000L CSR Bioreactor

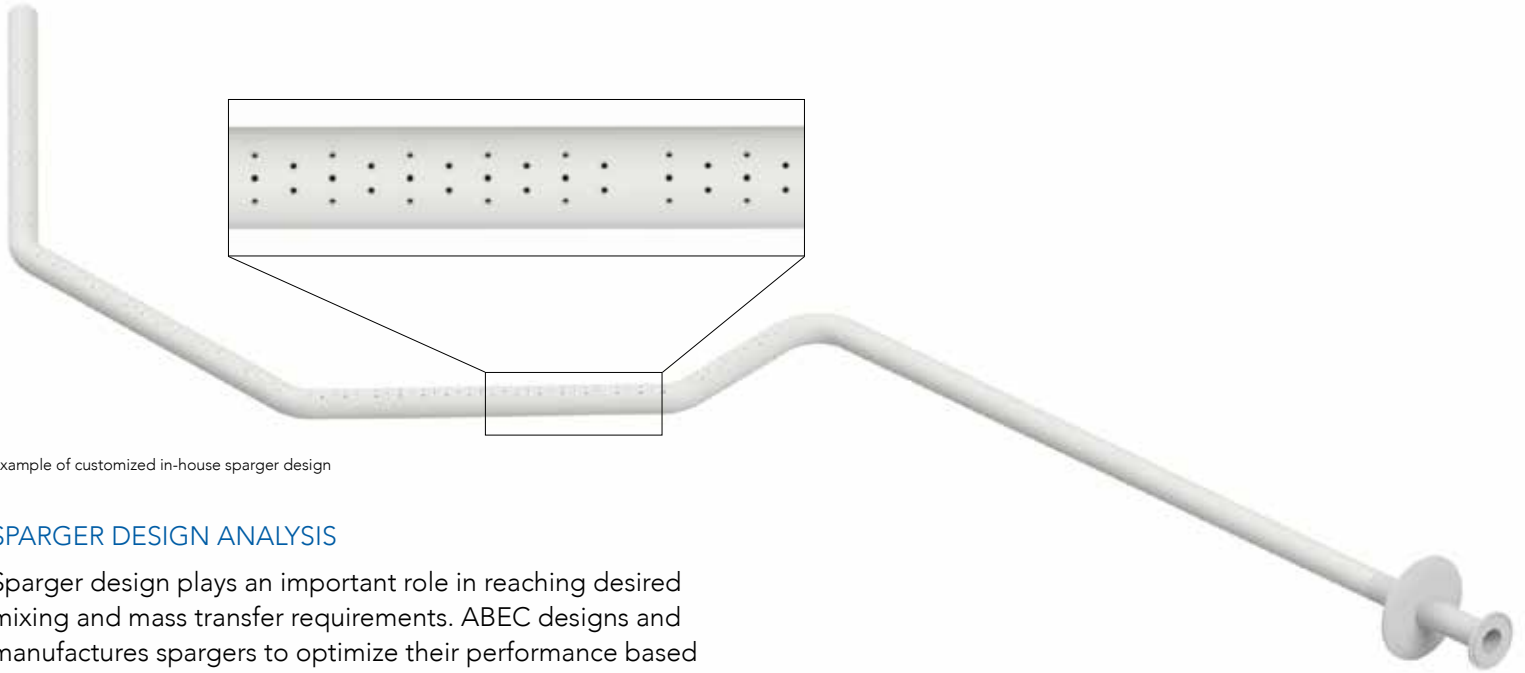
## LAB OR FIELD MIXING STUDIES

ABEC conducts process evaluation tests in-house or at the customer's site location. These tests are performed at various scales, ranging from development to production. ABEC has access to a wide range of reactor geometries to conduct scaled-down equipment studies. Outputs from lab or field mixing studies include:

- Blend time
- Surface vortex characterization
- Gas dispersion
- Power input
- Gas fluid mixing & velocity
- Mass transfer coefficient ( $K_L a$ )
- Oxygen transfer rate (OTR)
- $\text{CO}_2$  stripping
- Heat transfer coefficient
- Agitator selection/optimization
- Physical characterization



In-house sparger design performance testing



Example of customized in-house sparger design

### SPARGER DESIGN ANALYSIS

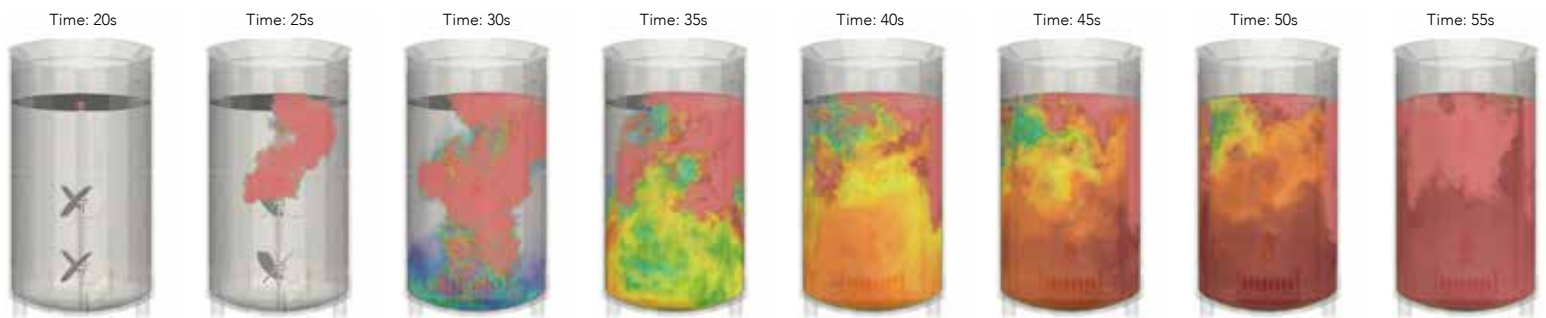
Sparger design plays an important role in reaching desired mixing and mass transfer requirements. ABEC designs and manufactures spargers to optimize their performance based on a specific process, testing the designs at ABEC's in-house reactor lab or the customer's facility on their process equipment. ABEC reviews and compares sparger designs to make recommendations based on the process requirements and customer goals. Data points collected during ABEC's sparger design analysis include:

- Gas exit velocity (GEV)
- Sparger hole utilization
- Bubble size
- Mass transfer
- Impeller flooding

### RESULTS

ABEC provides a final report that details the objectives, test/model protocols, analysis, and results from the study. With vast industry experience and knowledge, ABEC can recommend the next steps and process improvement options.

*Mixing and Mass Transfer Studies require preparation work to understand your needs, design and manufacture equipment, and schedule time in the mixing lab. To learn more about ABEC's Mixing and Mass Transfer Studies, contact ABEC for more information.*



Blend time example of 4,000L CSR Bioreactor