NEWSLETTER

VisiMix

Scaling-Up Emulsification Using Multi-Stage In-Line Rotor–Stator Devices

No.12- February 2026

Introduction

Emulsification is a critical unit operation in many chemical, pharmaceutical, and specialty manufacturing processes, where product performance and stability are strongly influenced by droplet size distribution. While pilot-scale trials can demonstrate technical feasibility, scaling up to higher throughputs often introduces challenges such as increased droplet coalescence, non-uniform energy dissipation, and loss of product consistency.

In-line Rotor–Stator Devices (RSDs) are widely used for continuous emulsification due to their high shear capability in compact designs; however, maintaining emulsification efficiency during scale-up requires careful evaluation of equipment design and operating conditions.

This case study presents the application of **VisiMix RSDE** for scaling up an oil-in-water emulsification process using a **multi-stage in-line rotor–stator system**. By combining pilot-scale validation with mathematical modeling, VisiMix RSDE was used to predict droplet size distribution, evaluate coalescence effects, and optimize a three-stage RSD configuration capable of higher production rates without compromising emulsion quality. The study highlights how simulation-driven design reduces reliance on trial-and-error experimentation and enables confident, low-risk scale-up of continuous emulsification processes.

Process Objective

The objective of this study was to **scale up a continuous in-line emulsification process from pilot to plant scale** while maintaining emulsion quality achieved under pilot operating conditions. The process involved production of an **oil-in-water emulsion at a fixed oil-to-water ratio of 3:7**, stabilized using a mild emulsifier. Using **VisiMix RSDE,** the study evaluated the suitability of a **three-stage in-line rotor–stator device (RSD)** for achieving consistent droplet size and stable emulsification at higher production throughput.

The Challenge

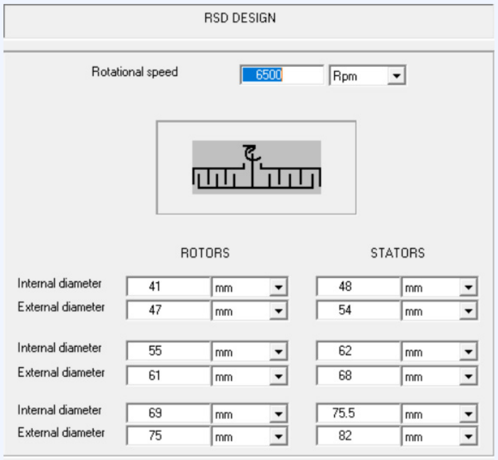
Scaling up continuous emulsification from pilot to plant scale presents several technical challenges:

- Maintaining droplet size and distribution while increasing throughput.
- Preventing droplet coalescence at higher flow rates.
- Translating single-stage pilot performance to plant-scale operation.
- Selecting an appropriate multi-stage in-line RSD configuration without extensive trial-and-error.
- Predicting emulsification performance and droplet size distribution prior to equipment implementation.

VisiMix Simulation Approach

Step-I: Pilot Plant Simulation – *Single-Stage In-Line RSD*

For the pilot study, the emulsification process was simulated in VisiMix RSDE using a single-stage in-line rotor–stator device (RSD) operating at a rotational speed of 6500 rpm. The RSD geometry was defined based on the pilot equipment, including rotor and stator diameters, to accurately represent the hydrodynamic and shear conditions during emulsification.



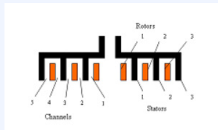


Figure: VisiMix RSDE pilot plant simulation inputs showing the single-stage in-line RSD design operated at 6500 rpm, along with its schematic configuration.

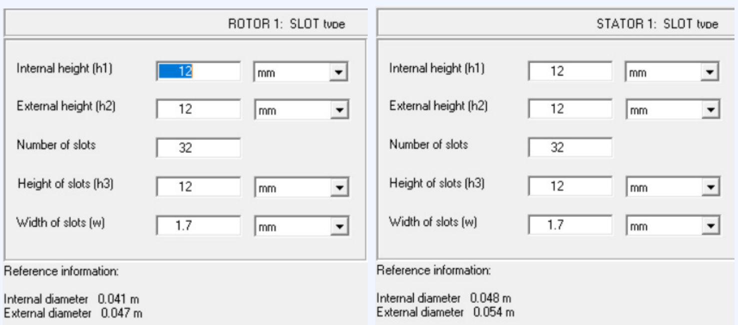


Figure: Slot-type rotor and stator geometric inputs

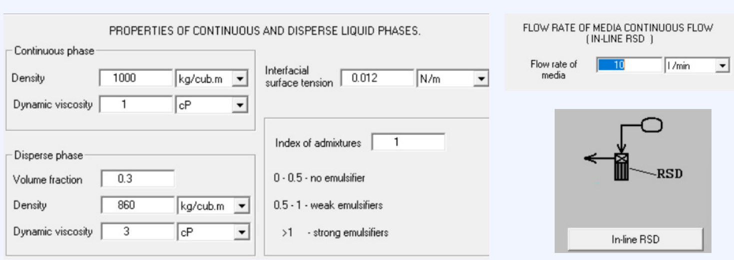


Figure: VisiMix RSDE inputs for pilot single-stage in-line RSD simulation, including phase properties and flow rate.

The pilot plant simulation using a **single-stage in-line RSD** was successfully established in VisiMix RSDE and used as a validated baseline for scale-up. Based on this validated model, plant-scale emulsification was evaluated using a **three-stage in-line RSD** configuration.

Step-2: Plant Simulation – *Three-Stage In-Line RSD*

To meet the increased production capacity while maintaining emulsion quality, plant-scale emulsification was evaluated using a **three-stage in-line rotor–stator device (RSD).**

The multi-stage configuration was modeled in **VisiMix RSDE** to achieve progressive droplet size reduction and minimize coalescence at higher flow rates. Simulations were performed at a flow rate of **50 L/min**, using the same liquid properties and formulation as the pilot study to enable direct comparison between pilot and plant performance.

The plant-scale simulation was carried out sequentially, starting with Stage-1 of the three-stage in-line RSD, with geometry, operating speed, and rotor-stator slot dimensions defined in VisiMix RSDE.

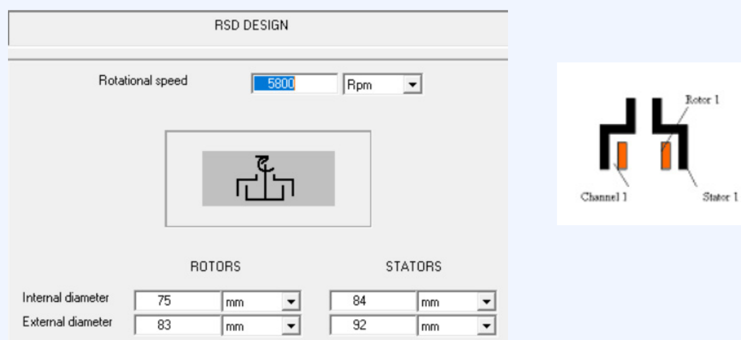


Figure: Stage-1 rotor–stator configuration

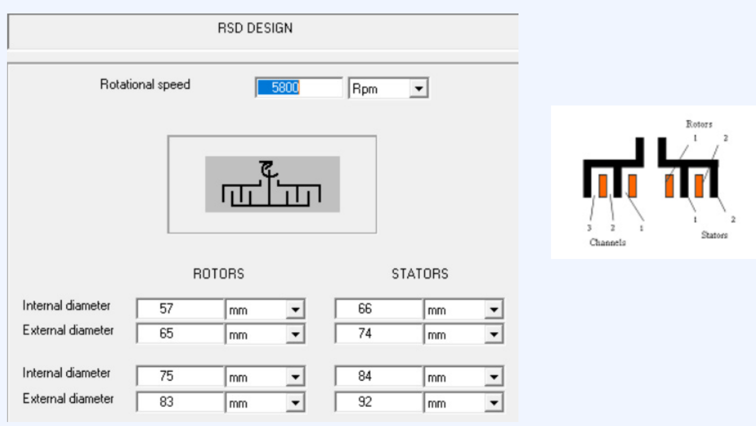
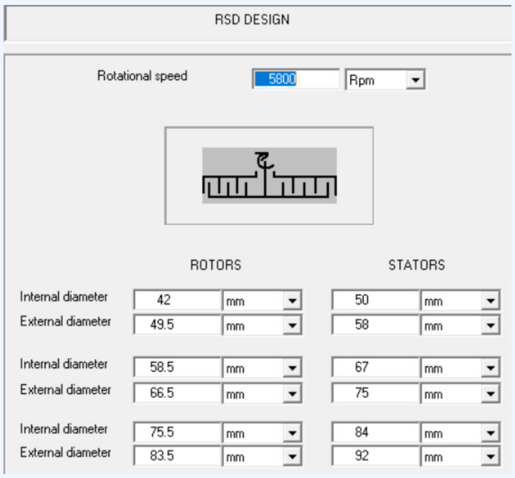


Figure: Stage-2 rotor–stator configuration



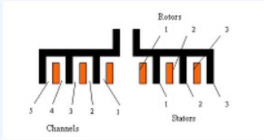


Figure: Stage-3 rotor–stator configuration

The **three-stage in-line RSD** configuration was fully defined in VisiMix RSDE, with each stage modeled sequentially to represent progressive emulsification under plant-scale operating conditions.

KEY SIMULATION RESULTS

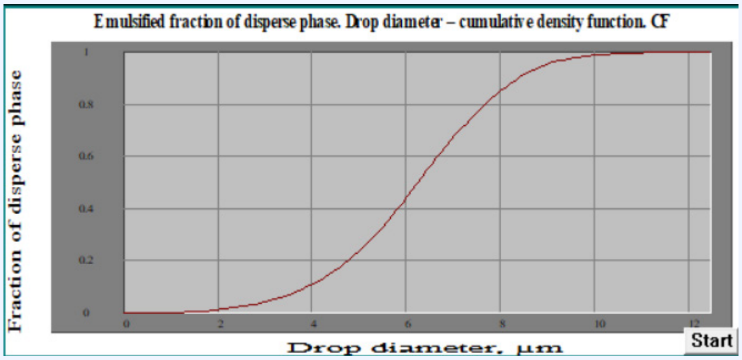
The VisiMix RSDE simulations clearly demonstrate the effectiveness of multi-stage in-line emulsification in maintaining droplet size while scaling up throughput.

- The **pilot plant simulation** using a single-stage in-line RSD predicted a **mean droplet size of 6.22 µm**, in good agreement with pilot observations.
- At plant scale, the **three-stage in-line RSD** showed progressive droplet size reduction across successive stages:
  - **Stage-1:** Mean droplet size of **61.9 µm**
  - **Stage-2:** Mean droplet size reduced to **10.4 µm**
  - **Stage-3:** Final mean droplet size of **5.61 µm**
- The final droplet size at plant scale was **comparable to, and slightly better than, the pilot-scale result,** despite operation at significantly higher flow rates.

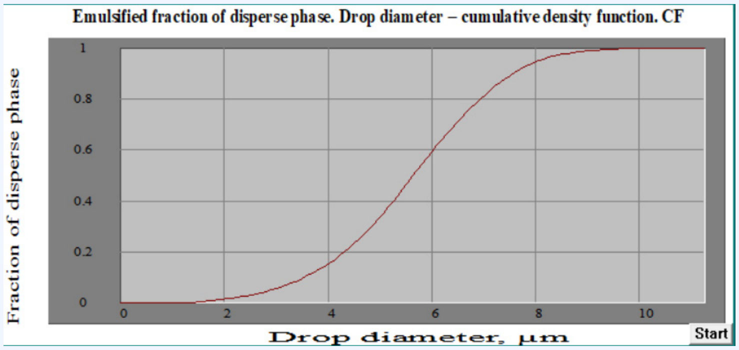
These results confirm that the three-stage in-line RSD configuration is capable of achieving the desired emulsion quality at plant scale and validate the suitability of VisiMix RSDE for reliable emulsification scale-up.

In addition to mean droplet size, **VisiMix RSDE cumulative distribution function (CF) plots** were used to evaluate droplet size distribution for both pilot and plant-scale emulsification.

- The **pilot-scale CF plot** shows a narrow droplet size distribution, with the majority of droplets below the target size range, confirming stable emulsification under pilot conditions.
- The **plant-scale CF plot** (three-stage in-line RSD) indicates progressive improvement in droplet size distribution across stages, with the final stage achieving a distribution comparable to the pilot case.
- The final plant-scale distribution confirms that **multi-stage in-line emulsification** effectively compensates for higher throughput, maintaining droplet size control.



Pilot plant



Plant

The CF plots confirm that the three-stage in-line RSD achieves droplet size distribution at plant scale comparable to pilot performance.

CONCLUSION

- **VisiMix RSDE reliably predicted emulsification performance** across both pilot and plant scales.
- Pilot-scale simulations using a single-stage in-line RSD closely matched experimentally observed droplet size results.
- **Multi-stage in-line emulsification** enabled progressive droplet size reduction at higher throughput.
- **A three-stage in-line RSD** achieved droplet size and distribution at plant scale comparable to pilot performance.
- **Cumulative droplet size distribution (CF) plots** visually confirmed improved control of droplet size.
- This simulation-driven approach reduced scale-up uncertainty and enabled confident, rapid equipment selection while minimizing experimental cost, development time, and trial-and-error.