Scalable Agitated Baffle Reactor (SABRe): From Batch to Continuous Flow via Integration of Tanks-in-series for Process Intensification

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Highlights

- SABRe streamlines CSTRs in series, retaining benefits without their complexities.
- SABRe reduces chemicals use, energy consumption, and waste, lowering carbon footprint by 25%.
- SABRe achieves 48-fold reduction in reactor volume at equivalent production rates to batch reactors.

1. Introduction

The imperative to transition from inefficient batch processing to continuous manufacturing in the chemical industry has become increasingly apparent, driven by the need for heightened operational efficiency and sustainability. Traditional batch processes suffer from downtime during equipment maintenance, resource wastage, and environmental impact. Continuous manufacturing emerges as a solution, promising reduced waste, enhanced control, and overall efficiency improvements. In this transformative landscape, the Scalable Agitated Baffle Reactor (SABRe) emerges as a pioneering technology, uniquely combining the efficiency of continuous processing with the operational flexibility of batch reactors.

Diverging from conventional batch processing, SABRe presents a novel approach to chemical manufacturing, specifically addressing the inefficiencies associated with multiple stirred tank reactors in series [1]. Its innovative design integrates agitators and baffles, creating a dynamic environment that facilitates continuous mixing and efficient heat and mass transfer, enabling significant process intensification. The project, in collaboration with Stoli Chem and Robinson Brothers, demonstrates the practical application of SABRe in intensifying specific industrial processes. The results highlight SABRe’s paradigm shift in scale efficiency, featuring a substantial 48-fold reduction in reactor volume that emphasises significant intensification. Furthermore, this achievement is accompanied by a 13% decrease in chemical use, a 9% reduction in waste, and a noteworthy 75% cut in energy consumption. Consequently, it leads to a 25% decrease in carbon footprint.

2. Methods

To assess SABRe's performance against batch production, a comparative study was conducted on the synthesis of zinc diisononyldithiocarbamate (commercially known as Arbestab Z – a rubber accelerator) under identical conditions to its batch production at Robinson Brothers. Due to a confidentiality agreement, the specific reaction details for the synthesis of Arbestab Z are not disclosed.

The residence time distribution (RTD) of SABRe was determined through tracer experiments [2]. A non-reactive tracer (KCl) was introduced at the inlet, and the resulting breakthrough curve was analysed using the tanks-in-series model to characterise the reactor's flow dynamics. Fourier-transform infrared spectroscopy (FTIR) was used to monitor the reaction, and properties of Arbestab Z, such as melting point, ash content, and particle size distribution, were measured. Additionally, the Life Cycle Assessment (LCA) analysis was performed with openLCA to compare environmental impacts of the SABRe and batch processes.

3. Results and discussion

The SABRe system, depicted in a 'tanks-in-series' model (Fig. 1a), consolidates multiple CSTRs into a singular reactor, providing enhanced control over residence time. Unlike traditional batch methods with inherent inefficiencies, such as multiple steps, component charging, and extended reaction times. A key attribute of the SABRe system is its capacity to streamline the process, eliminating inefficiencies present in traditional batch systems. In our investigation, the SABRe system demonstrates a 50% reduction in residence time compared to traditional batch processes, whilst resulting in a significant improvement in Arbestab Z yield (95-98%), surpassing the 84-94% range in traditional batch methods. All properties of Arbestab Z produced in the SABRe align with commercial production standards.

The LCA analysis reveals a nearly 25% reduction in global warming potential with the continuous SABRe process (Fig. 1b), emitting 7.06×10^6 kg CO_2-Eq compared to 9.4×10^6 kg CO_2-Eq in batch processes. Clearly, SABRe exhibits a markedly lower carbon footprint. A comprehensive assessment across environmental impact categories underscores SABRe's suitability for industries prioritising ecological responsibility and sustainability, consistently demonstrating lower environmental impacts than batch processes. Additionally, the SABRe achieves a substantial 48-fold reduction in reactor volume, whilst maintaining equivalent production rates compared to batch reactors.

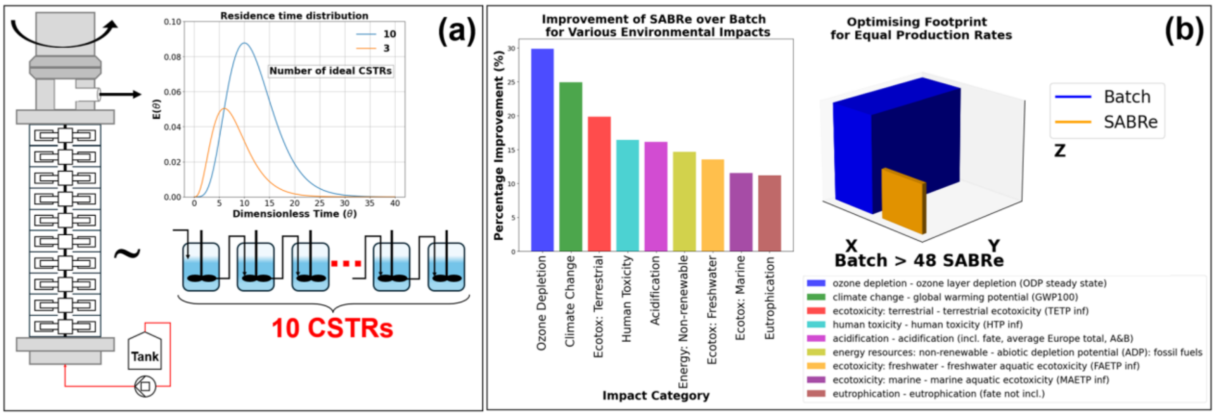

Figure 1. (a) SABRe reactor, (b) Improvement of SABRe over batch reactors.

4. Conclusions

The transition from inefficient batch processing to continuous manufacturing stands out as a pivotal advancement highlighted by our findings. The SABRe system seamlessly integrates the efficiency of continuous processing with the operational adaptability of batch methods. Notably, it achieves a substantial increase in ArbZ yield (95-98%), surpassing the typical 84-94% range in batch processes. Moreover, SABRe demonstrates a significant reduction in both economic and environmental costs associated with chemical manufacturing. By consolidating the advantages of continuous processing into a single reactor, it not only enhances operational control compared to the traditional series of CSTRs but also contributes to noteworthy energy, resource, and carbon savings.

References

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Keywords

SABRe; tanks-in-series; process intensification.