Process intensification in an Elastic Foam-bed Reactor: hydrodynamics, mass transfer and modeling

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Highlights

- Dynamic EFR increases liquid holdup up to 70% in counter-current operation.
- Pressure drop in EFR shows periodic oscillations synchronized with foam compression.
- EFR enhances gas–liquid mass transfer with kla 1.5 time higher than static FFR.

1. Introduction

Elastic Foam-bed Reactor (EFR)[1], [2] was developed by combining polyurethane foam's elastic properties with crankshaft technology. The reactor consists of a column packed with two polyurethane foam blocks, forming a structured bed whose properties are modulated through piston-driven compression and decompression cycles. This motion promotes efficient gas-liquid mixing even at low velocities and allows continuous operation with complex systems like slurries or solid residues.

2. Methods

To evaluate the reactor in gas–liquid counter-current and co-current downflow configurations, hydrodynamic and mass transfer studies were conducted. An experimental methodology was implemented to determine three key parameters of multiphase reactor performance over a range of fluid velocities from 0.5 to 11.5 mm/s:

1. The liquid holdup (ε_l) and axial dispersion ($D_{ax,l}$), determined using a KCl tracer method where a Dirac pulse was injected and monitored by conductimetry (Fig 1, b).
2. The pressure drop, monitored with a differential pressure gauge positioned upstream and downstream of the reactor.
3. The overall gas–liquid mass transfer coefficient (k_la), obtained via oxygen stripping in deionized water using nitrogen and recorded with an oxygen probe.

These experiments were conducted under two operating modes (Fig 1, a): (I) the Fixed Foam-bed Reactor (FFR) mode, where the foam remains static; and (II) the dynamic Elastomeric Foam Reactor mode, operated at a crankshaft frequency of 1 Hz and an amplitude of 3.8 cm (corresponding to 80% compression at maximum). The results were benchmarked to compare the innovative EFR with the conventional FFR, assessing its potential for multiphase applications.

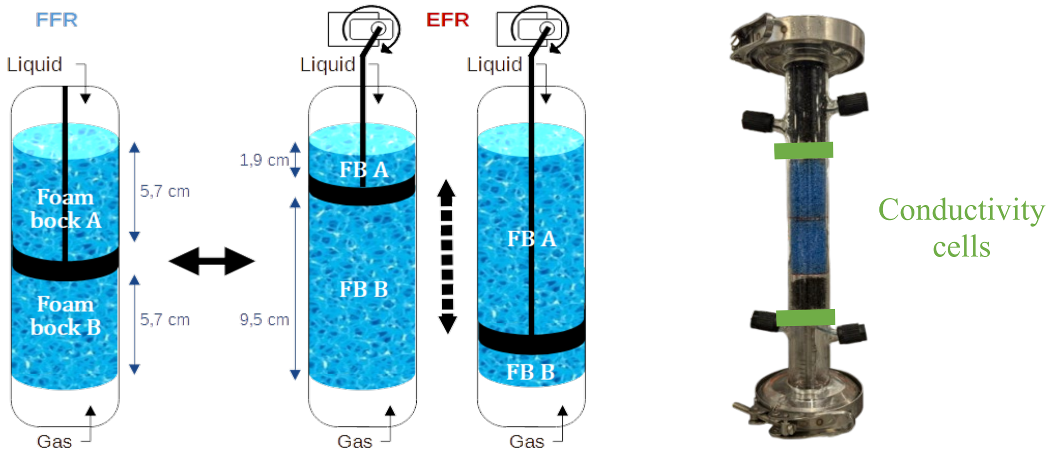

Figure 1, a: Schema of the two operationg modes FFR and EFR in counter-current, **b**: Picture of the reactor

3. Results and discussion

The experimental campaigns produced highly encouraging results. The liquid holdup and liquid axial dispersion were obtained from the Residence Time Distribution (RTD) using the Dispersed Plug-Flow

(DPF) model. In co-current and FFR counter-current, the liquid holdup exhibited typical TBR values around 20%[3], but increased significantly in counter-current EFR, reaching nearly 70% (Fig 2).

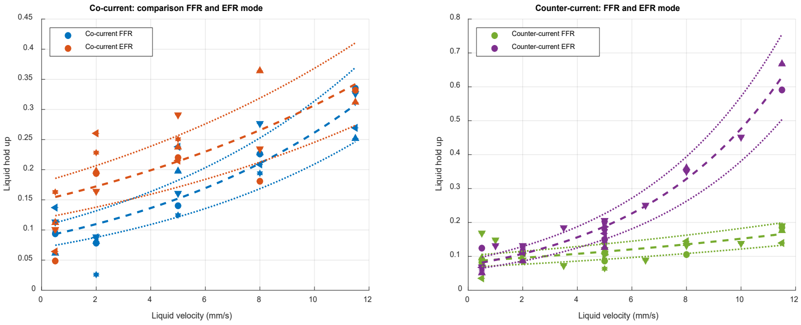

Figure 2: Liquid holdup drop under co-current and counter-current flow in FFR and EFR modes

In counter-current EFR mode, the pressure drop exhibited sinusoidal oscillations (Fig 3, b) whose period is synchronized with the crankshaft movement. This characteristic behavior was described using momentum balance and the Darcy–Forchheimer equation, incorporating the liquid holdup from the RDT and the instantaneous piston velocity to capture the transient flow regime induced by the periodic compression cycles.

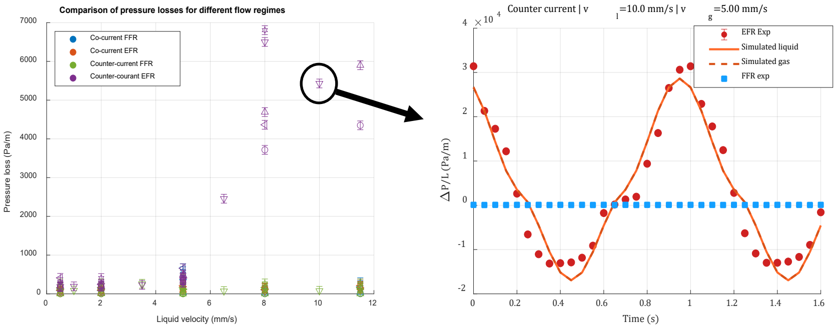

Figure 3, a: Pressure drop under co-current and counter-current flow in FFR and EFR modes, **b** : Pressure drop and correlation at liquid velocity of 10 mm/s and gas velocity of 5.0 mm/s in FFR and EFR modes

The overall mass transfer performance obtained using DPF reactor model, liquid holdup and axial dispersion is markedly improved. Under identical operating conditions, EFR exhibits kla values 1.5 times higher than in FFR for both flow configurations. This improvement reflects reduced diffusive limitations, as dynamic compression enhances interfacial renewal and gas–liquid contact.

In addition to the experimental work, reactor modelling, using the DPF reactor model provided valuable insights into the system's hydrodynamics and guided performance optimization. Correlations for kla and pressure drop helped establish predictive tools that will support future scale-up and operational optimization of the EFR concept.

4. Conclusions

A full comparison between static and dynamic modes for counter-current and co-current configurations will be presented for various flow rates during the conference.

Future work will focus on a three-bed reactor arranged in series, with a total bed height ranging from 12 to 60 cm, is currently being studied for pilot-scale implementation.

References

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Keywords
Process intensification; multiphase reactor; elastic bed; modeling