Prototype reactors and their viability for sorption-enhanced processes: continuous sorbent flux fluidized bed reactors (CSFFBR)

Simona Renda[1]*, Mario Leclercq[2], Jaime Soler[1], Javier Herguido[1], Miguel Menéndez[1]

[1]*Aragón Institute for Engineering Research (I3A), University of Zaragoza, C/ Mariano Esquillor s/n 50018, Zaragoza, Spain;*

[2]*National Superior Engineering School of Industrial Technologies, University of Pau and Pays de l'Adour, Rue Jules Ferry BP 7511, CEDEX, 64075 Pau, France*

**Corresponding author: srenda@unizar.es*

Highlights

- Novel CSFFBR enables continuous sorbent regeneration without process interruption.
- Optimized reactor geometry minimizes catalyst loss and enhances segregation control.
- Catalyst circulation (<4 wt.%) ensures reduced deactivation and longer lifetime.

1. Introduction

The increasing demand for efficient and sustainable chemical processes has driven the development of intensified systems capable of integrating reaction and separation in a single unit. Nevertheless, the process limitation lays into the saturation of the sorbent, which requires a regeneration step. Both in fixed bed reactors and fluidized bed reactors in fluid catalytic cracking (FCC)-like configuration, the catalyst is subjected to repeated regeneration cycles, which significantly shorten its operational lifetime. To overcome these drawbacks, a novel reactor design is proposed in this research: the Continuous Sorbent Flux Fluidized Bed Reactor (CSFFBR). This configuration integrates the benefits of sorption enhanced reaction with continuous sorbent feeding and removal, thereby supporting uninterrupted operation and enhanced control over reaction/sorption and regeneration zones.

2. Methods

In the CSFFBR, the reaction occurs in a bubbling fluidized bed, into which fresh sorbent particles are continuously fed. The catalyst and sorbent are selected or engineered to possess sufficiently different particle characteristics – such as density or size – to ensure the occurrence of their segregation within the reactor. Typically, the denser or bigger material remains near the bottom of the reactor, while the lighter or smaller solid migrates toward the top; either the lower section or the free surface of the fluidized bed can be employed to selectively remove the sorbent from the reaction environment. Once isolated, the sorbent can be regenerated externally, enabling continuous operation without disrupting the catalyst or reaction flow. A scheme of the proposed cycling application is given in Figure 1.

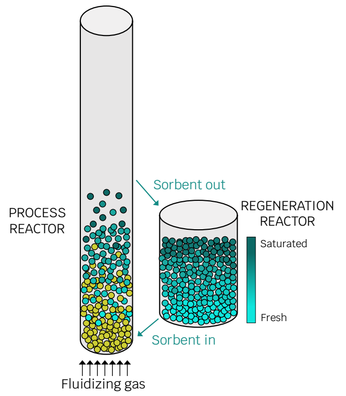

Figure 1. Example of the CSFFBR coupled with regeneration unit.

3. Results and discussion

Several factors influence the behavior of a CSFFBR and can be grouped into three main categories. The first concerns the physical properties of the solids, such as particle density and size, which are key to segregation phenomena. The second involves operating parameters, including the type of fluidizing gas, relative velocity (u_R), solids mixing ratio, and, in continuous systems, the sorbent feed rate. The third relates to system geometry, since both reactor configuration and the placement of sorbent inlets can significantly affect concentration profiles and overall reactor performance. To evaluate this last parameter, three prototype reactors were designed and built, as shown in Figure 2. The three prototypes were tested at a relative velocity of 1.5 using a mixture containing 20 wt.% initial catalyst. The solid exiting the system was collected and analyzed at regular time intervals, and the catalyst fraction in the outlet was determined to enable comparison among the configurations. Configurations with a side entrance exhibited a significant loss of catalyst from the reactor bed to the outlet stream, which is particularly pronounced for configuration (b). This behavior is likely associated with the system fluid dynamics, and specifically related to the presence of a non-symmetrical element, such as the inlet or the tube. Macroscopic observations revealed that the lateral solid inlet promoted the formation of a preferential channel within the fluidized bed, effectively dividing it diagonally into two distinct regions: a more vigorously fluidized zone near the inlet, characterized by larger bubbles, and a quieter zone where the bed was merely expanded. The latter region appeared to be enriched in catalyst, whereas the former consisted predominantly of sorbent particles. Nevertheless, the highly fluidized region operated beyond the segregation regime, implying that catalyst particles entrained into this zone were likely carried out of the system.

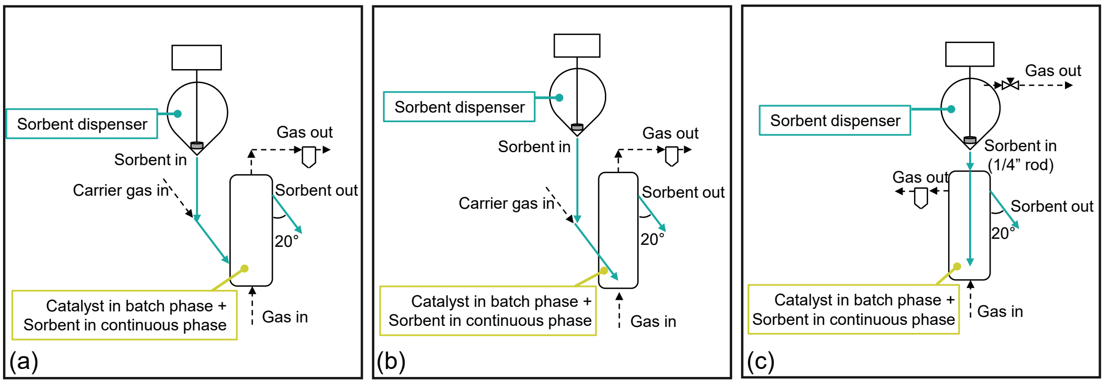

Figure 2. Prototype reactors for CSFFB applications: (a) wall lateral entrance; (b) centered lateral entrance; (c) axial entrance.

Further optimization of the operating conditions to be applied to obtain optimal segregation in configuration (c) was subsequently performed. A complete segregation between catalyst and sorbent was never obtained; this means that a certain amount of catalyst left the reactor in any tested condition. However, in a circulating system like the one proposed in Figure 1 this would mean that a certain amount of catalyst undergoes regeneration together with the sorbent. Although the regeneration step is detrimental for the catalyst as it can lead to sintering and general loss of activity, this would still affect a relatively small portion of the whole catalyst employed for the reaction. The simulation of a circulating system by the addition of a fixed amount of catalyst into the sorbent dispenser allowed to find a condition in which a steady state is reached, and only 3.4 wt.% of the catalyst circulates throughout the system undergoing regeneration, as displayed in Figure 3.

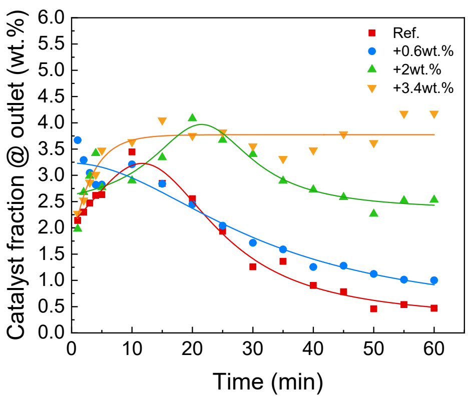

Figure 3. Simulation of a recirculating system: evolution over time of the catalyst fraction in the outlet solid stream as a function of the catalyst weight fraction in the solid inlet

4. Conclusions

This work has presented the design, development, and experimental assessment of a novel Continuous Sorbent Flux Fluidized Bed Reactor (CSFFBR) for sorption-enhanced processes. The proposed concept successfully integrates the fluid-dynamic advantages of fluidized beds with the continuous circulation of one of the solids selectively, enabling uninterrupted operation and external regeneration of the sorbent. This approach avoids the drawbacks of conventional fixed bed and fluidized bed configurations, such as cyclic regeneration and catalyst degradation due to thermal stress. After optimizing the reactor geometry and the operating conditions, continuous operation experiments showed that only a small fraction of catalyst (<4 wt.%) circulated with the sorbent stream, suggesting that catalyst deactivation in a closed architecture would be significantly mitigated compared to conventional systems.

Keywords
Fluidized bed reactors; sorption-enhanced processes; continuous sorbent flux; segregation