Process Intensification of Low-Temperature Syngas Production *via* the LT-rWGS: A Fluidized-Bed Reactor with Continuous Sorbent Feeding (CSF)

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Abstract

This study explores the process-intensification of green carbon-monoxide (CO) synthesis —an essential building block for the petrochemical sector and a promising vector for the energy transition— using a sorption-enhanced fluidized-bed reactor (SEFBR) continuously supplied with fresh sorbent (CSF).

Introduction

Anthropogenic climate change is driven primarily by the rising atmospheric concentration of greenhouse gases, notably CO_2. Since the Industrial Revolution, fossil-fuel combustion and deforestation have disturbed the planetary carbon balance. Accelerating an energy transition based on renewable sources and increased efficiency —especially in transport and heavy industry— is therefore imperative. A complementary avenue is CO_2 valorisation, whereby the gas is upgraded into synthetic fuels (e-fuels). A recently patented technology developed by the CREG group —hydrogenation of CO_2 in a fluidized-bed reactor equipped with Continuous Sorbent Feeding (CSF)— has demonstrated pronounced rate enhancement by maintaining operation under quasi-steady sorption conditions [1].

Process intensification can target higher energy efficiency, greater production capacity, and/or reduced plant footprint. Depending on the strategy employed, intensification may be continuous or finite. Productivity gains can arise from advanced catalysis, reactor design [2], or the selective removal of reaction coproducts [3]. The present work combines the latter two approaches: an innovative reactor configuration integrates in-situ adsorption of coproducts to extend the intensification window.

The system employs a fluidized bed in which the solid sorbent is fed and withdrawn continuously. Because adsorption capacity is inherently finite, sustained intensification requires a well-segregated bed that retains the catalyst in the reactor while allowing partially saturated sorbent to exit. Vertical segregation separates two granular solids of different density and size: the heavier and/or larger "*jetsam*" (the catalyst) preferentially goes downward, whereas the lighter and/or smaller "*floatsam*" (3A zeolite acting as sorbent) migrates upward and is discharged out of the reactor. Freshly regenerated zeolite is continuously introduced, and partially spent material is simultaneously removed, thereby maintaining constant intensification.

The target reaction is the reverse water-gas shift (*rWGS*), in which CO_2 reacts with H_2 to yield CO and H_2O. The CO thus produced serves as an intermediate for sustainable aviation and marine fuels via *Fischer-Tropsch* or methanol synthesis — key routes for hard-to-electrify sectors.

Experimental and Discussion

Experiments were conducted in a "Sorption-Enhanced Fluidized-Bed Reactor with CSF" (SEFBR+CSF) featuring two lateral ports for sorbent feed and withdrawal (**Figure 1**). Two operating modes were compared: (**i**) conventional, without sorbent, and (**ii**) CSF-intensified, with continuous zeolite replacement.

The experiments were carried out with a fixed mass of BASF K3-110 catalyst (W_{cat} = 17.4 grams). The reduced superficial gas velocity was held constant at $u_r = u/u_{mf} = 1.08$ to preserve identical segregation conditios throughout the test matrix. Because the minimum fluidization velocity (u_{mf}) is a function of pressure (P) and temperature (T), the *Weight Hour Space Velocity* (*WHSV*) varied with temperature, decreasing as the reactor temperature. All trials were performed at atmospheric pressure (P_{atm}). Prior to the reaction stage, the catalyst was reduced by passing a 50/50%^{v} N_2/H_2 mixture at 300 mLSTP min^{-1} trough the bed at 260 ºC for 1 h. Subsequently, the bed was heated to the designated operating temperature under an inert atmosphere (100%^{v} N_2).

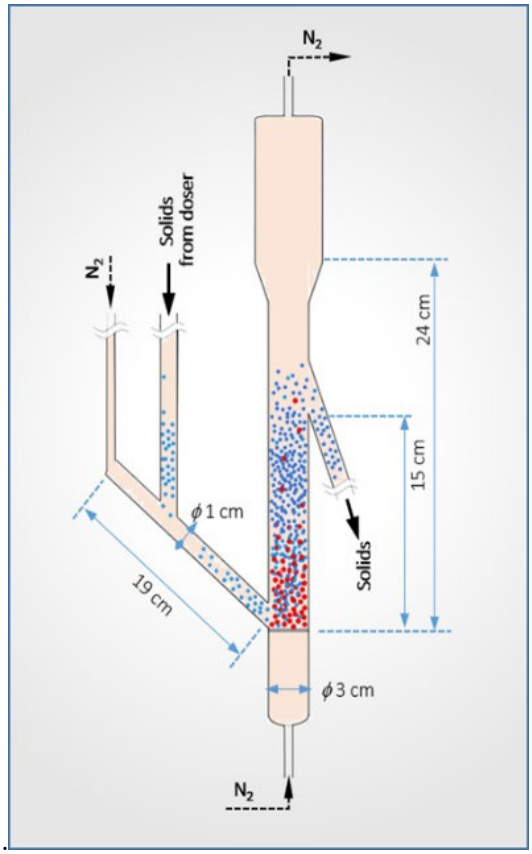

Figure 1. Schematic of the Sorption-Enhanced Fluidized-Bed Reactor with Continuous Sorbent Feeding (SEFBR-CSF).

Figure 2 illustrates the impact of process-intensification through Continuous Sorbent Feeding (CSF) on CO_2 conversion. The CSF operating window is delineated by two vertical red lines. Across the entire temperature range tested, the CSF configuration (blue triangles) yields CO_2 conversions consistently higher than those obtained with the conventional setup (pink stars). The enhancement is most pronounced during the intensification period, where CO_2 conversion surpasses the thermodynamic-equilibrium limit (indicated by the horizontal black line). Once sorbent feeding ceases, however, CO_2 conversion gradually decreases until it matches the same values observed in conventional runs, underscoring the direct dependence of catalytic performance on continuous sorbent renewal.

Conclusions

The novel CO_2 hydrogenation concept was successfully validated at laboratory scale. Operation with continuous sorbent feeding CSF achieved process efficiencies surpassing the thermodynamic equilibrium limit, demonstrating the potential of sorbent-assisted fluidized-bed intensification for green CO production.

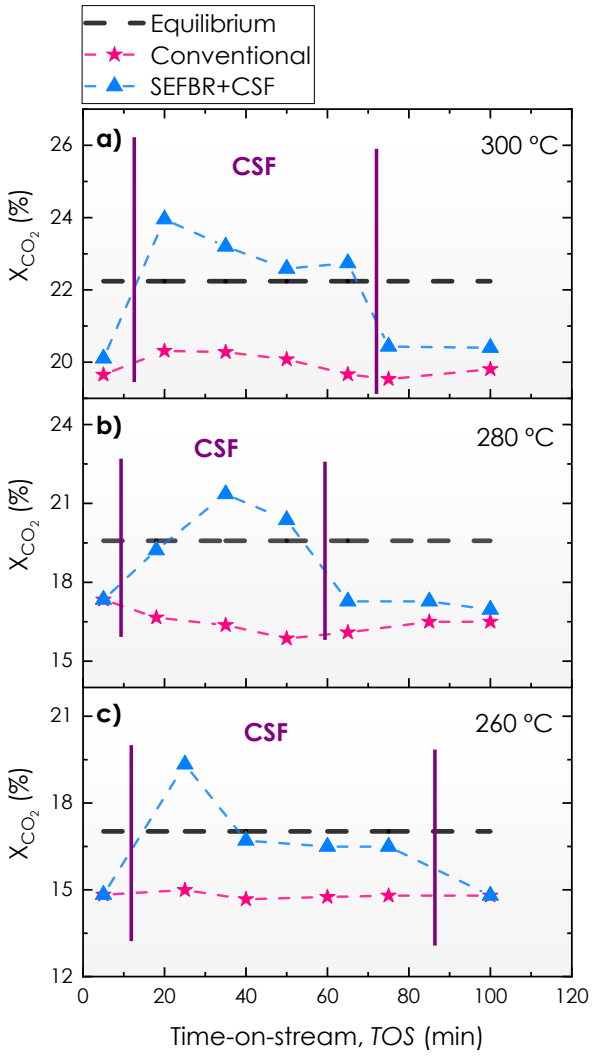

Figure 2. Experimental CO_2 hydrogenation results at (**a**) 300 °C, (**b**) 280 °C, and (**c**) 260 °C; reduced superficial gas velocity u_r = 1.08

References

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