Intensified Methanol Synthesis in a Fluidized Bed Reactor with Continuous Sorbent Feeding (SEFBR+CSF)

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INTRODUCTION

The main aim is to intensify green methanol production through a modified reactor configuration based on a fluidized bed reactor with continuous sorbent feeding. In this system, a selective sorbent is continuously introduced to remove reaction products in situ, thereby shifting the reaction equilibrium toward methanol formation and enhancing overall conversion. As shown in figure 1.

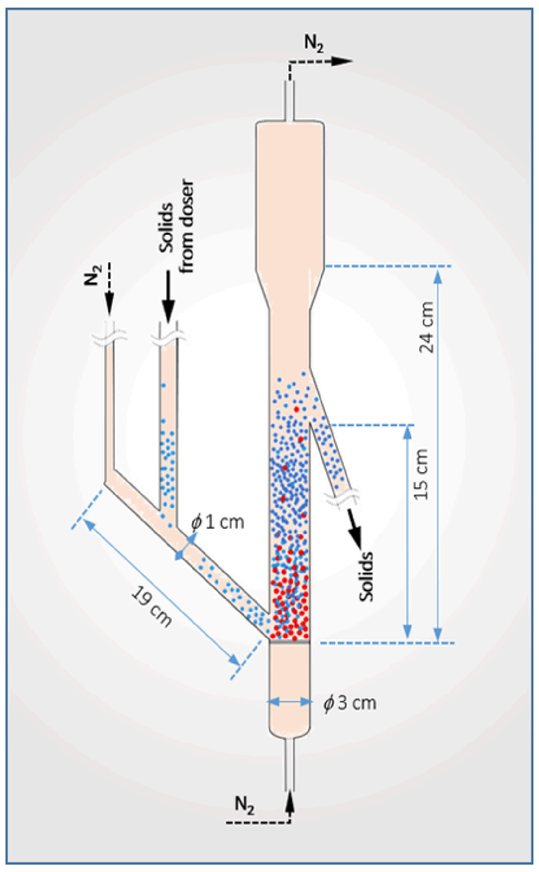

Figure 1. Experimental set up of the SEFBR+CSF system

The feedstock for these experiments should be CO_2 captured from hard-to-abate industrial processes, while the H_2 must be produced from renewable sources to meet the objectives of Power-to-Fuels systems. In addition, the energy input should also be renewable in order to fully align with the project's sustainability goals. This concept is illustrated in Figure 2.

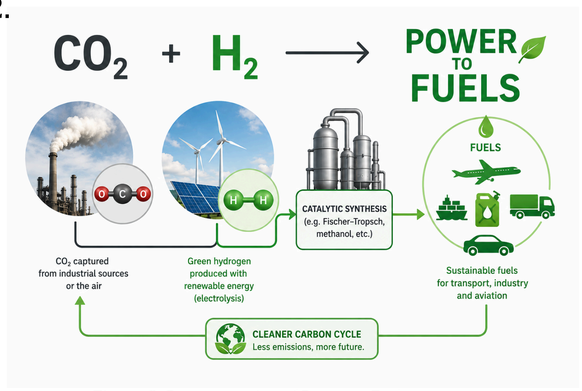

Figure 2. Representation of Power to Fuels process

FLUID-DINAMIC EXPERIMENTS

In order to determine the appropriate size of the catalyst and sorbent particles, experiments were carried out over a reduced velocity range between 1.08 and 1.50, where the reduced velocity is defined as:

$$U_r = \frac{U}{U_{mf,catalyst}} \qquad \text{[Eq. 1]}$$

Different catalyst sizes were tested over a fixed range of zeolite particle diameters. The mixing index was evaluated for each velocity condition to assess the experimental performance. A graphical representation of the mixing index is shown in Figure 3 and calculated according to [Eq. 2]. The corresponding results are presented in Figures 4 to 6.

$$IM = \frac{\int_0^{H^*} |X_J^* - X_J| dz}{\int_0^{H^*} |X_J^* - X_{J0}| dz} \qquad \text{[Eq. 2]}$$

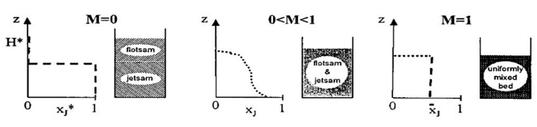

Figure 3. Graphical representation of the mixing index.

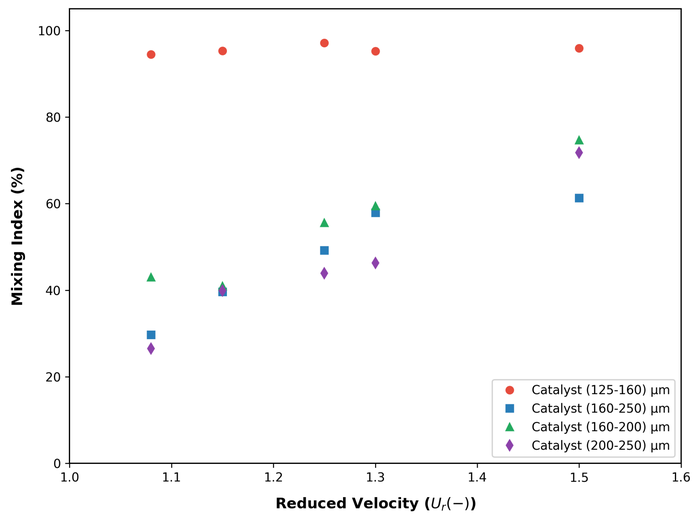

Figure 4. Mixing index of zeolite particles (75–106 µm) for different catalyst sizes.

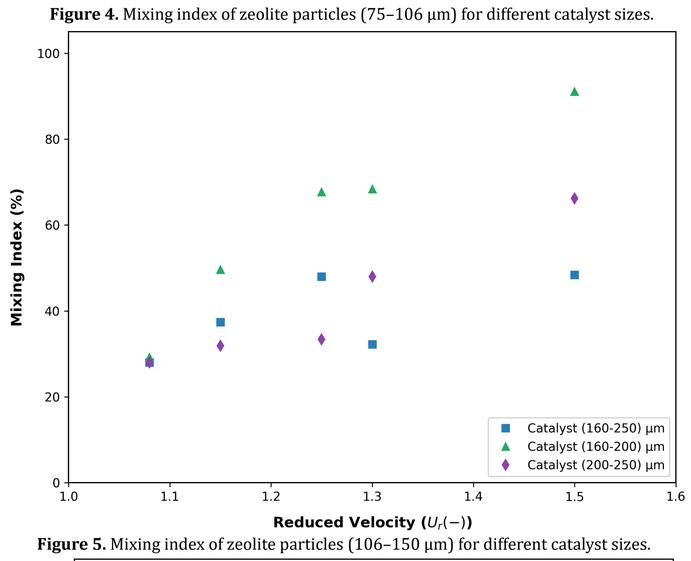

Figure 5. Mixing index of zeolite particles (106–150 µm) for different catalyst sizes.

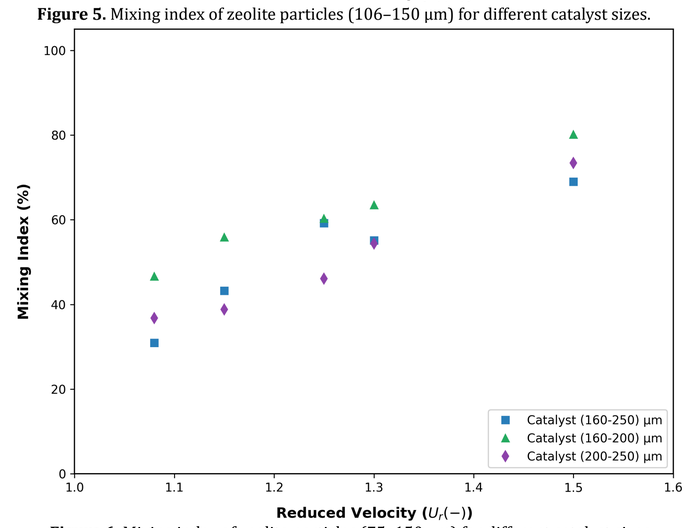

Figure 6. Mixing index of zeolite particles (75–150 µm) for different catalyst sizes.

During the sorbent feeding analysis, blockage of the sorbent inlet due to sealing issues affected the experimental procedure. Consequently, the experiments were conducted using zeolite 3A particles within a size range of 75–150 µm and catalyst particles within a range of 200–250 µm.

This condition led to a reduction in the catalyst fraction inside the reactor. To overcome this issue, the reduced inlet velocity was adjusted to 1.04, and an additional 3.11% of catalyst was mixed with the zeolite. The corresponding results are presented in Figures 7, 8 and 9.

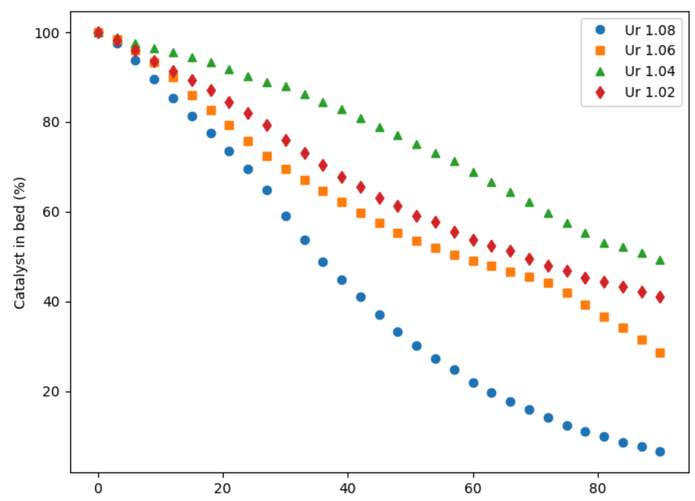

Figure 7. Evolution of catalyst content in the bed for different reduced velocities

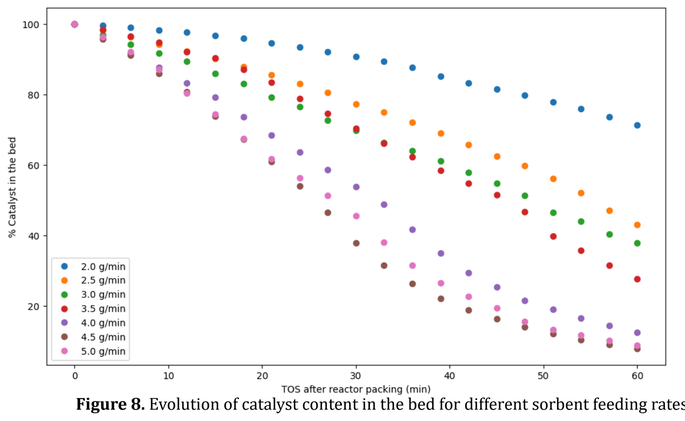

Figure 8. Evolution of catalyst content in the bed for different sorbent feeding rates

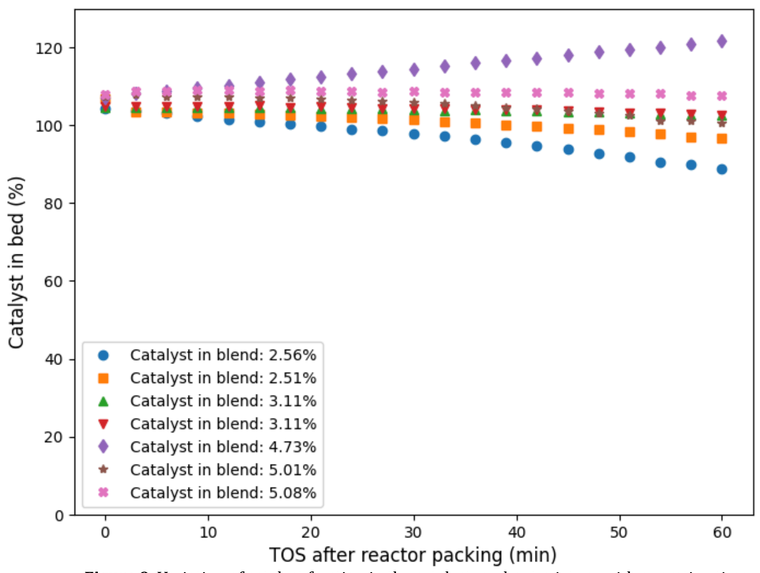

Figure 9. Variation of catalyst fraction in the catalyst–sorbent mixture with operating time

Table 1. Parameters of operation

Parameter	Value
Pressure (bar)	20
Temperatura (ºC)	230 - 270
H_2/CO_2 ratio	3
TOS (min)	90
Catalyst loading (g)	20
Catalyst	BASF K3 - 110
Reduced velocity (-)	1,04
Sorbent	Zeolita 3A
Sorbent feeding (g min^{-1})	2.5 (3.11% wt catalyst)

Expected reactions in the system:

$$CO_2 + 3 \cdot H_2 \rightleftharpoons CH_3OH + H_2O \qquad \text{[r. 1]}$$

$$CO_2 + H_2 \rightleftharpoons CO + H_2O \qquad \text{[r. 2]}$$

$$CO + 2 \cdot H_2 \rightleftharpoons CH_3OH \qquad \text{[r. 3]}$$

RESULTS

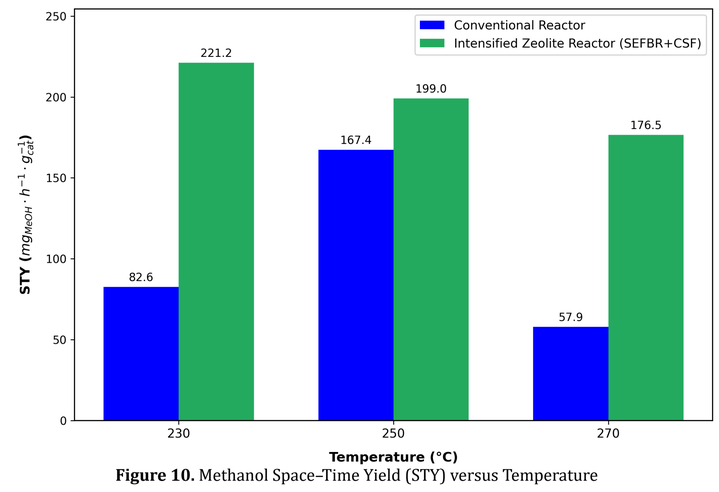

Figure 10. Methanol Space–Time Yield (STY) versus Temperature

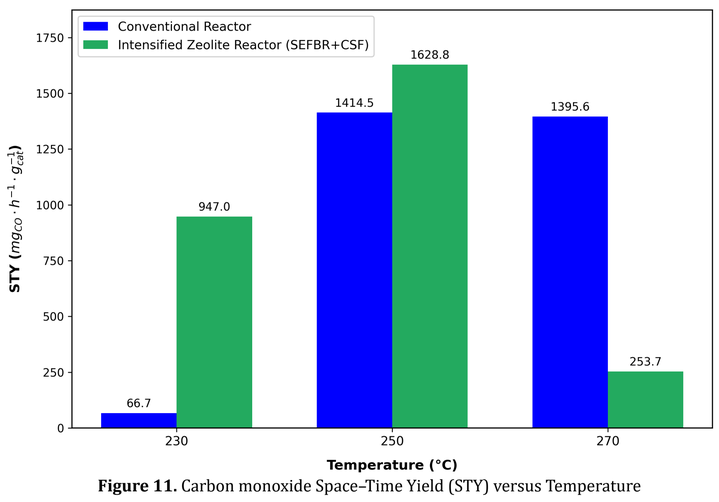

Figure 11. Carbon monoxide Space–Time Yield (STY) versus Temperature

KEY FINDINGS

- Optimal operation at U_r = 1.04
- Zeolite 3A successfully selected, with negligible methanol sorption
- Continuous sorbent feeding achieved
- Enhanced CH_3OH productivity
- rWGS reaction confirmed and promoted

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