Overcoming the constraints of tubular Fischer-Tropsch reactors with the adoption of highly conductive packed metal foams

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Highlights

- Conventional packed-bed FTS reactors are constrained by the onset of thermal runaway.
- Highly conductive Al-foams packed with catalyst pellets are tested in the FTS.
- The performances of the structured catalyst are compared with those of the packed pellets.
- Limited axial T-gradients prove the potential of packed foams to manage heat removal.

1. Introduction

In the last decade, the interest in the Fischer-Tropsch synthesis (FTS) has been considerably renewed in view of exploiting both associated and remote natural gas fields. The FTS is a highly exothermic reaction with a standard reaction enthalpy of -165 kJ/mol. The heat removal from the reactor is thus a key issue for the development of an intensified FTS reactor [1]. The use of conventional packed-bed reactors (PBRs) is severely limited by heat removal causing a series of constraints which limit the catalyst performances. The poor heat transport properties in PBRs lead to non-isothermal operation of the reactor. This negatively affects the catalyst selectivity and, in the worst case, leads to the onset of thermal runaway [2].
In line with these premises, the efficient thermal management in the latest modular reactor technology suitable for the FTS on a compact scale (< 3000 BPD) is a key issue [2]. In this regard, Politecnico di Milano recently proposed the adoption of honeycomb catalysts with high-conductivity supports within externally cooled multitubular fixed-bed reactors [3]. In this way, the heat transfer is strongly enhanced because the primary radial heat exchange mechanism is changed from convection to conduction within the thermally connected solid matrix of the honeycomb monolith [3].
For the first time in the scientific literature, we propose herein to enhance the heat transport properties of a FTS packed bed reactor through the adoption of highly conductive open-cell metal foams packed with catalyst pellets. These materials were recently proposed as a strategy to intensify heat transfer in strongly endo- and exo-thermic processes [4], but were never used for the FTS. They exploit the same conductive heat transfer mechanism of the monolithic substrates but, in addition, they have the advantage of enabling radial mixing within their structure, thus enhancing both heat transfer and flow uniformity [4]. Our strength is also the adoption of "packed" open-cell foams, which can overcome the inherently limited catalyst inventory of washcoated structured reactors.

2. Methods

Open-cell Al-foam (40 PPI and $\varepsilon_{foam} \approx 0.886$) with a cylindrical shape (d_{foam}= 2.78 cm and l_{foam}= 2 cm) is provided by ERG AEROSPACE (Figure 1). One axial through hole of 0.32 cm diameter is located at the centerline for the insertion of the stainless steel thermowell (1/8'' O.D.), protecting sliding J-type thermocouple. Once the foam is loaded in the tubular reactor (2.78 cm I.D.) and the thermowell is put in place, the foam is totally packed with 9 g of home-made $Co/Pt/Al_2O_3$ (18wt.% of Co and 0.1wt.% of Pt) catalyst (d_{pellet}= 300 μm). The packed-foam is then tested in the FTS in a lab-scale plant at 190-220 °C, 25 bar, H_2/CO^{in}= 2 mol/mol, GHSV= 6410 cm^3(STP)/h/g_{cat}. The catalytic performances of the structured catalyst, as well as the T-gradient along the catalytic bed, are compared with those of the packed pellets.

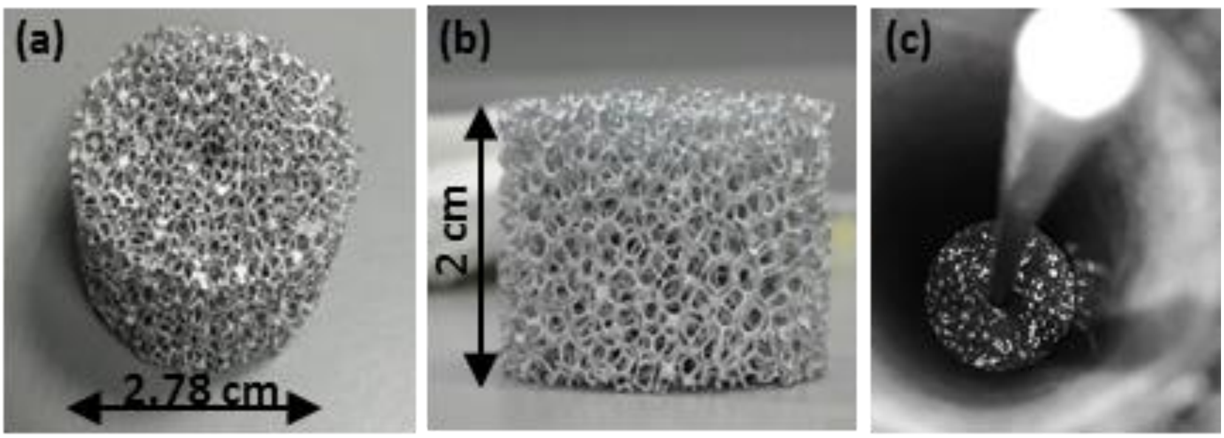

Figure 1. (a, b) Al-foam before loading it into the reactor; (c) Al-foam loaded into the reactor and packed with $Co/Pt/Al_2O_3$ catalyst

3. Results and discussion

The performances of the $Co/Pt/Al_2O_3$ catalyst were initially assessed in a tight packed-bed reactor (1.1 cm I.D) at diluted conditions so to avoid hot-spots along the catalytic bed. Interestingly, the $Co/Pt/Al_2O_3$ catalyst showed outstanding performances (i.e. CO conversion of 30 % and α_{C15+}= 0.905 at 200°C, 25 bar, H_2/CO^{in}= 2 mol/mol, GHSV= 6410 cm^3(STP)/h/g_{cat}). However, when the same experiment was carried out with 9 g of "pure" catalyst randomly loaded in the same reactor used for the packed-foam (2.78 cm I.D.), an abrupt increase of the catalyst temperature occurred, eventually leading to thermal runaway. Notably, this didn't happen with the adoption of the packed-foam reactor, which allowed running the process with a good temperature control. Limited axial temperature profiles were found along the catalytic bed, showing the excellent ability of this material to manage the heat removal issue. The Al-foam removed effectively the heat generated by the strongly exothermic FTS carried out over the highly active catalyst used.

4. Conclusions

The results obtained in this work clearly prove that highly conductive packed foams represent a promising route for the intensification of compact FTS reactors. They grant enhanced heat transport properties, which enable highly active catalysts to work under operating conditions that boost the process selectivity.

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Keywords

"Fischer-Tropsch synthesis"; "Structured catalysts"; "Conductive packed foams"; "Heat transfer"