Promotion of heat transfer in compact Fischer-Tropsch tubular reactors using structured conductive internals: a pilot scale study

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Highlights

- Aluminum foam and POCS tested in tubular Fischer-Tropsch pilot reactor.
- Cobalt catalyst micropellets packed inside structured conductive internals.
- CO conversion > 70% reached with overall heat transfer coefficient > 1300 $W/m^2/K$.

1. Introduction

In recent years, the Fischer-Tropsch synthesis (FTS) is receiving a primary attention in view of its capability of upgrading distributed resources (stranded gas, biomass and CO_2), while producing green fuels and chemicals. One of the key-aspects to address in this regard is how to intensify FTS reactors, aiming at the reduction of the plant footprint, improvement of the flexibility, boost of the productivity and decrease of energy consumption [1].

The FTS is characterized by high reaction enthalpy ($\Delta H°_R \approx$ -165 kJ/mol_{CO}) and is highly sensitive to temperature, therefore, an optimal heat management is mandatory. This aspect becomes pivotal in the scaling down of multi-tubular reactors, wherein the convective heat transfer mechanism is severely limited due to the low gas velocities. A poor heat management affects the catalyst, leading to shorter lifetime due to strong thermal gradients, and additionally shifts the reaction selectivity toward methane and light hydrocarbons. For these reasons, the intensification of heat transfer in compact reactor is particularly necessary to enable operation of this highly exothermic reaction at the compact scale.

In this context, structured reactor internals have been proposed as a promising solution. A structured internal consists in a pre-shaped cellular continuous 3D matrix, with a well-defined geometry, which is introduced inside a tubular reactor [1]. In this work, open-cell foams (OF) [2] and Periodic Open Cellular Structures (POCS) [3] have been studied. The supports are manufactured of highly conductive materials, in order to improve the heat transfer properties enabled by the conduction inside the continuous solid matrix. Since Fischer-Tropsch synthesis requires high catalyst inventory, catalyst microspheres are packed inside the structured internal voids, placed inside a short tubular reactor.

In this work we report the performances of a pilot tubular structured reactor using highly conductive OF and 3D printed POCS packed with active catalyst particles, and we show that this enables the operation of the FTS at the small scale with CO conversion in excess of 70% and high chain growth probability values. Tests with a conventional packed-bed are also reported for comparison purposes.

2. Materials and Methods

In this work, aluminum open-cell foams [2] and POCS with skin [3] have been tested. Al-6101 foams and $AlSi_{10}Mg$ 3D printed POCS have been packed with 20% wt. Co/Al_2O_3 catalyst particles (dp=0.3 mm), occupying the central 20 cm of a stainless steel jacketed tubular reactor 1m long and ~1 inch I.D.. Structured internals have been tested under Fischer-Tropsch relevant conditions: 25 barg, H_2/CO=2.1, GHSV= 4 $Nl/h/g_{cat}$. Different reaction temperatures (T_{cool}) have been tested to explore the thermal behavior of the structured reactor. At each tested condition, axial temperature profiles along the centerline (T_{cat}) as well as the skin temperature of the reactor (T_{wall}) have been assessed, with the detailed composition of the outlet stream. The collection of data enabled the estimation of an overall heat transfer coefficient characteristic of the adopted structured internals.

3. Results and discussion

Figure 1 shows how the application of structured internals inside compact tubular reactor permits to enhance the overall heat transfer rates in the pilot FTS reactor. Figure 1(a) shows the estimates of the

overall heat transfer coefficient for the tested configuration. The coefficient is obtained by linear regression of the data of reaction heat duty Q_{sup}, normalized by the lateral heat exchange surface, plotted against the average difference between the axial catalyst temperature (T_{cat}) and the coolant temperature (T_{cool}) in each tested condition. The adoption of an Al foam as structured internal allows to obtain an overall heat transfer coefficient (U) of 450 W/m^2/K, which is an outstanding value when compared to 50 W/m^2/K of the packed bed (PB) configuration without internals. A subsequent improvement in the overall heat transfer coefficient is achieved by the adoption of Al POCS with skin, reaching the value of 650 W/m^2/K. Tailoring of the internal geometrical parameter of the POCS enabled reaching an overall heat transfer coefficient of 1300 W/m^2/K: the 3D printing technique used to manufacture the POCS enables additional degrees of freedom in the internal design with respect to the foam, that allows to optimize the performances of the material.
The different heat transfer coefficients of packed-foams and packed-POCS reactors result in different CO conversion achievable at the compact scale, figure 1(b). In the packed-bed case, ~5% CO conversion was reached before the thermal runaway of the reactor, while in the tailored packed POCS with the skin experiment CO conversion values as high as 70% were feasible. The enhanced overall heat transfer coefficient resulted in milder temperature profiles at high reaction duties, reaching a C_5^+ yield in excess of 0.35 g/h/g_{cat} in the best condition.

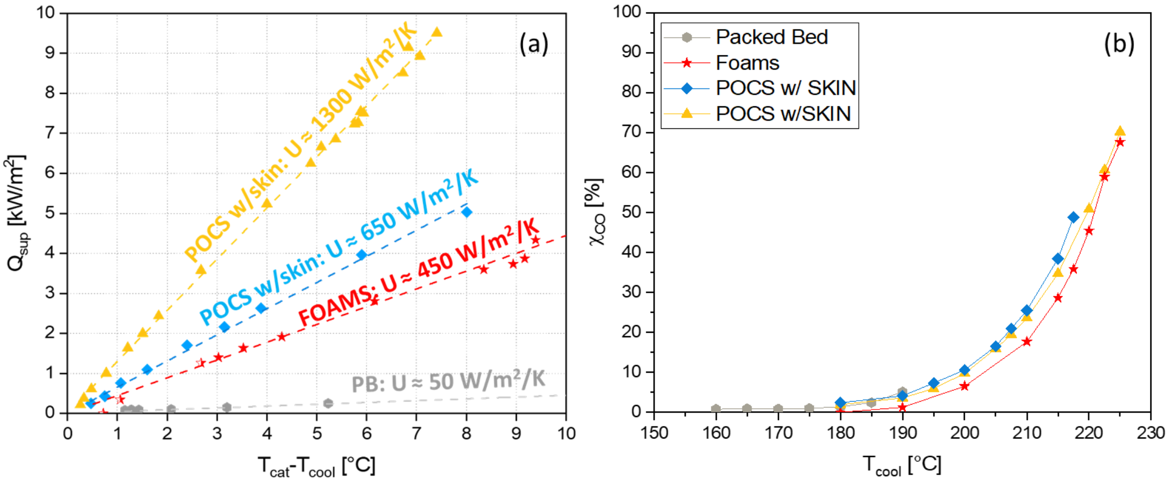

Figure 1. (a) Specific heat duty vs (catalyst temperature – coolant temperature); **(b)** CO conversion vs coolant temperature.

4. Conclusions

We show here, through experimental tests at the pilot scale, that conductive structured internals with tailored geometrical parameters ensure outstanding heat transfer coefficients, CO conversions and product selectivity in FTS tubular reactors. Such an intensification is granted by an additional mechanism to overall heat transfer, namely heat conduction inside the continuous metallic solid matrix of the cellular internals. Packed-POCS are better than packed-foams, which in turn are much better than packed-bed. Indeed, the 3D printing manufacturing of POCS enables additional degrees of freedom in the internal design of this matrix (such as the presence of an outer skin) with respect to the foam, that can be used to optimize the performances of structured reactors. In perspective, metal-based structured internals are highly attractive for strongly exo- and endothermic, heat transfer limited catalytic processes, and may lead to the development of new, intensified reactor technologies.

References

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Fischer-Tropsch synthesis, Structured reactors, POCS, foams.