HIGHLY CONDUCTIVE "PACKED FOAMS" FOR THE INTENSIFICATION OF CATALYTIC PROCESSES IN COMPACT TUBULAR REACTORS

Carlo Giorgio Visconti, Gianpiero Groppi, and Enrico Tronconi*
Politecnico di Milano
Milano, Italy, 20156

Abstract

Our group in Milano has recently proposed the adoption of "packed foam" reactors, a breakthrough reactor technology exploiting highly conductive open-cell foams packed with small catalyst pellets to intensify highly exo- and endo-thermic catalytic processes. In this work we assess the heat transfer performances of those reactors and compare them to those of tubular reactors loaded with conventional packed beds of pellets and with bare open-cell foams. We show that packed foams take advantage from a synergism between the enhanced conductive heat transfer in the solid structure of the foam and the convective heat transfer in the packed-bed. These results are particularly promising in view of the development of a new generation of intensified compact reactors for non-adiabatic catalytic applications.

Keywords

Packed foams, Process intensification, Structured reactors.

Introduction

Engineering the heat management is of primary importance for the intensification of many important strongly exothermic or endothermic catalytic processes (Tronconi et al., 2014). In this regard, one of the most promising options proposed in the last decade is represented by non-adiabatic multitubular reactors loaded with highly conductive open-cell foams (also known as sponges) washcoated with the catalyst material (Bianchi et al., 2012). In those reactors the reaction heat is effectively exchanged between the catalyst and the thermoregulating medium primarily via an efficient heat conductive mechanism in the thermally connected structure of the substrate. Due to the thin catalyst layer, however, this technology often suffers from an insufficient catalyst inventory, which may limit the potential advantages associated with the adoption of conductive structured reactors. Also, the catalyst loading and unloading in the reactor, as well as the replacement of the spent active phase, are particularly critical in such a technology.

To overcome those issues we have recently proposed the adoption of "packed foam" reactors (Groppi et al., 2015). In those reactors, which are particularly interesting for compact scale applications (i.e. short tubes), the catalyst is loaded in the form of small pellets (e.g. microspheres) packed in the voids of a highly conductive open-cell foam. In this work we have assessed the heat transfer performances of those reactors and we have compared them to those of conventional packed beds of pellets and of bare open-cell foams.

Experimental

Comparative heat transfer experiments have been performed in a lab-scale test rig consisting of a finned stainless steel pipe (28 mm I.D.) placed in an oven, using

* To whom all correspondence should be addressed

three different types of packings: (i) packed beds of Al_2O_3 pellets with 0.3 mm diameter; (ii) bare open-cell foams made of two different materials (aluminum alloy 6101, Al-6101, and FeCrAlloy®, FeCrAlY), and with different geometries (cell densities 10-40 PPI and relative densities 5.5-6%); (iii) packed foams obtained by packing the Al_2O_3 pellets with 0.3 mm diameter within Al-6101 and FeCrAlY foams previously mentioned. During the experiments, carried out heating the oven at different temperatures (200-500°C), two different "cold" gases (He and N_2) at different flow rates (representative of those used in compact industrial reactors) have been fed to the reactor and steady-state axial and radial T-profiles inside the packings and at the pipe skin were measured.

Then, a classical 2D two-parameters pseudo-homogeneous heat transfer model has been fitted to the experimental results and the value of the effective radial conductivity and the wall heat transfer coefficient have been estimated for the three different packings. The value of the overall heat transfer coefficient was also calculated.

Results and Discussion

Figure 1 shows the estimates of the overall heat transfer coefficient U measured for the different packings at different process conditions. Lines are used to group 4 different packing configurations particularly relevant to be compared.

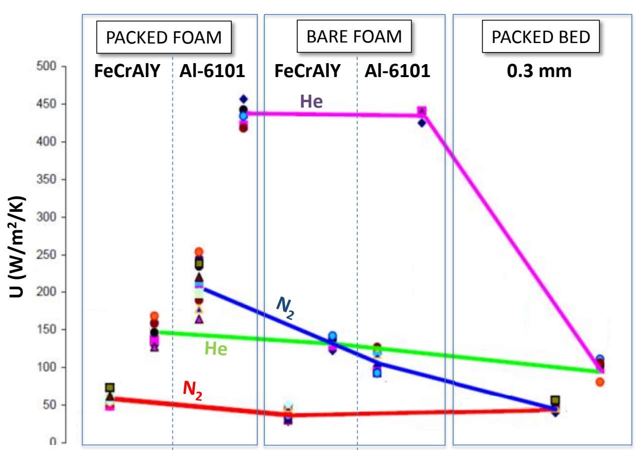

Figure 1. Heat transfer performances of different packings upon varying the flowing gas and its flow rate

Data show that at the adopted conditions heat transfer in a packed-bed is comparable to that in a low conductive bar foam (FeCrAlY) regardless the properties of the flowing gas. In this case, packed foam with a low conductive structured substrate does perform similarly to the corresponding packed-bed and bare foam. On the contrary, due to the high value of the effective radial conductivity (Bianchi et al., 2012), heat transfer in a highly conductive bare foam (Al-6101) is much better than in packed-bed, which on the contrary shows higher wall heat transfer coefficient at high flow rates (data not shown). In this case, a packed foam with a highly conductive structured substrate performs much better than the corresponding packed-bed and bare foams. This is well evident especially when a low conductive gas is used (N_2).

The performances of packed foams can be explained considering that such packings take advantage both of the enhanced conductive heat transfer in the solid structure of the foam (governed by the thermal conductivity of the foam material and by its relative density (Bianchi et al., 2012)) and of the convective heat transfer in the packed-bed (governed by the thermal conductivity of the gas phase and its velocity). The former mechanism, that is flow independent, controls both the effective radial conductivity (Bianchi et al., 2012) and the wall heat transfer coefficient (Bianchi et al., 2013) at low flow rates. The latter one further contributes to the overall heat transfer coefficient at high flow rates. A circuit of equivalent resistances has been identified to describe the heat transfer mechanisms within packed foams.

Conclusions

These results demonstrate that "packed foams" may be particularly advantageous in compact reactor applications requiring short tubes, in view of their flow-independent, conductive heat transfer mechanism which adds to the flow-dependent, convective heat transfer typical of packed-beds of pellets.

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