Improvement of the hydrodynamics in packed beds using new shape pellets.

Isabelle Pitault[1*], Amara Fezoua[2], Marie-Line Zanota[2], Marie Basin[3]*

1 Univ Lyon, Université Claude Bernard Lyon 1, CNRS, LAGEP UMR 5007, 43 boulevard du 11 novembre 1918, F-69100, VILLEURBANNE, France; 2 Univ Lyon , CNRS-CPE Lyon-UCBL, Laboratoire de Génie des Procédés Catalytiques, 43 bd du 11 Novembre 1918, 69616 Villeurbanne, France; 3 Air Liquide CRCD, 1 Chemin de la Porte des Loges, 78354 Jouy-en-Josas, France

**Corresponding author: isabelle.pitault@univ-lyon1.fr*

Highlights

- Different shapes of pellets are assessed to improve hydrodynamics in narrow packed beds.
- The fluid flow is oriented by holes and corrugations when the pellets are leaning of 45°.
- Pellets with holes and corrugations improve the pressure drop and the radial dispersion.
- The helices improve pressure drop, radial dispersion and internal mass transfer.

1. Introduction

The hydrogen production in steam methane reforming (SMR) processes involves narrow catalytic packed beds and high gas velocity (up to 3m.s^{-1}). The improving of reactor performances is limited by the high pressure drops induced by the use of pellets, by the wall and radial heat transfers and the mass transfer inside the catalytic pellets. All these transport phenomena are highly affected by pellets shape and the packing topology [1]. This project consisted in better understanding the hydrodynamics in packed bed when the packing was made of ring or pellets with holes. The pressure drop in packed-bed is classically estimated using the Ergun's equation [2] which is perfectly accurate for beads. But more recently Nemec and al. [3] showed that for non-spherical particles, the use of Ergun equation is not sufficient to predict the pressure drop through the beds. They suggest Ergun equation for particles with the same size (following the hydraulic radius concept), in a moderate flow rate and for a range of porosity ($0.35 < \varepsilon < 0.55$). This work show the difficulty of predicting the pressure drop in packed beds by using theoretical models, the best way to do this remaining the experiments. As for the pressure drop, the radial dispersion correlations have been established for beads at low fluid velocities and cannot be used in the SMR experimental conditions. Thus, this work was to perform experiments on SMR gas velocities with unconventional pellet forms, to assess the weight of holes, of corrugations on the pellets and of the orientation in the pressure drop and the radial dispersion. Moreover, this project allowed to propose optimized pellets with unconventional holes (such as cylinders with corrugated extern wall and with flake-shape holes), to put forward unconventional forms (such as helices) and to suggest a new approach to model the pressure drop based on the work of Whitaker [4].

2. Methods

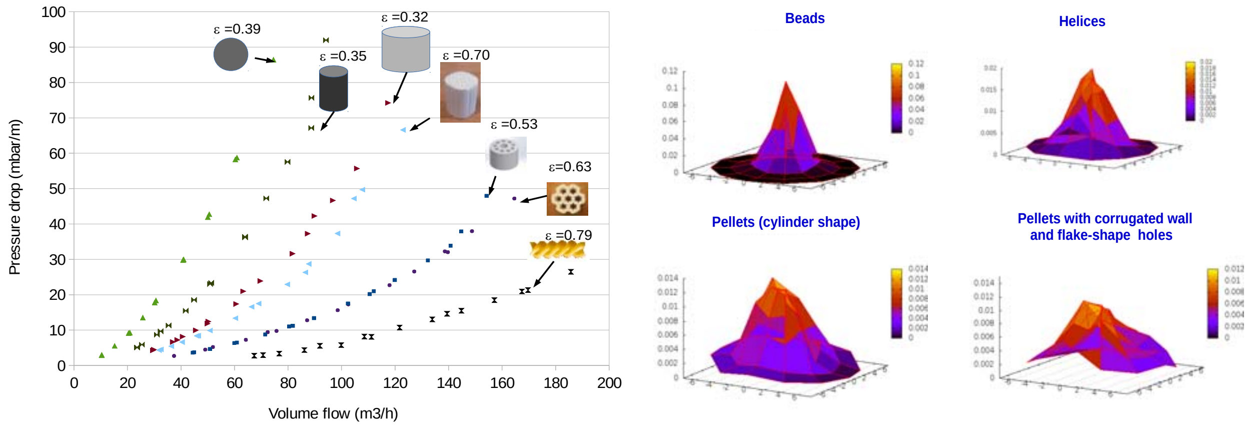
To characterize the packing, experimental methods were used: pressure drop measures, radial dispersion by methane tracing method for the hydrodynamics and the Image Processing from 3D-tomography analyses for the topology (porosity, orientations). The results given here allow to compare several shapes of pellets: beads, cylindrical pellets with different height/diameter ratios, cylindrical pellets with cylindrical holes (cylinders), cylindrical pellets with corrugated extern wall with no holes or with flake-shape cylindrical holes (called von Koch-Vauban (VKV)) and finally helices (such as fusilli pasta).

The pressure drop was measured in a test bench consisting of a tube of 15 cm diameter and 395.5 cm length (Vpacked bed = 46.9 L). Air was used as gas phase with a flow rate from 0 to 185 m^3/h (i.e. 0 to 2.9 m/s). There were 5 pressure measurement nozzles. The reactor was filled with sleeves or randomly. The flow was generated by a vacuum cleaner and measured with a calibrated cone using a speed sensor. For radial dispersion assessment, methane Dirac pulses were generated at the bed top of a smaller tube (15 cm diameter and 80.5 cm length). Methane concentrations were measured at the bed bottom on 54 sampling points using a FID (Flame Ionization Detector) specially designed par SRA company and controlled by the inlet valve. Each methane concentration curves were integrated to be compared.

For the 3D-tomography, the packed beds were performed in glass tube (10 cm diameter and 35 cm length) to allow the complete X-Ray scanning of the whole packed-bed. Specific Image Processing routines were written with Matlab® software. After the image thresholding, axial and radial porosity profiles were obtained by the simple counting of the black voxels in each 3D image section. Methods of object segmentation, specific to each pellet form, were developed to correctly separate each object.

3. Results and discussion

In general point of view (Figure 1a), the pressure drop decreases with the increasing bed porosity. For the cylindrical pellets, the presence of holes reduces the pressure drop but their effect is not evident comparing the cylinders and the VKV. However, the pressure drop induced by the helices is very close to the one estimated by Ergun equation using equivalent particle diameter. To understand the hole effect, we have blocked them by sticks, either obstructing all the holes, either keeping only the middle one or keeping only the ring of smaller holes. We observed the Darcy's term was negligible with respect to the Forchheimer's one and the addition of two or three Forchheimer terms (two for the middle and ring holes and one for the external porosity) modeled the pressure drop. The comparison of the weight of the terms in the equation showed more fluid passing through the holes than in the external porosity, and more through the middle hole than through the ring holes. The cylindrical holes also induced less pressure drop than the flake-shape holes, due to their high specific area. Moreover, the bed topology analysis showed the cylindrical pellets with a diameter/height ratio close to 1 mainly leaned with a 45° angle and this positively affected the radial dispersion, the fluid being oriented by the holes and the corrugations. The radial dispersion for helices was highly improved with respect to the beads but it remained a little bit lower than for the pellets (Figure 1b).



(a) (b)

Figure 1. Hydrodynamic behavior for some forms of interest (a) Pressure drop. (b) Methane concentration profiles at the bed outlet.

4. Conclusions

The hydrodynamics behavior in narrow catalytic packed bed can be improved by using large pellets with a diameter/height ratio close to 1, corrugations and same holes. The helices could also be another good alternative. They reduce pressure drop, induce radial flow with respect to beads and would have the advantage to reduce the internal mass transfer limitations due to their thinness.

References

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Keywords
Packed bed ; Pressure drop; Radial dispersion; Bed topology