Chemical Engineering Science 65 (2010) 504 – 510

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

Dynamics of filtration in monolith reactors using electrical capacitance tomography

Mohsen Hamidipour, Faïçal Larachi*

Department of Chemical Engineering, Laval University, Québec, Canada G1V 0A6

ARTICLE INFO

Article history:
Received 7 July 2008
Received in revised form 5 June 2009
Accepted 10 June 2009
Available online 18 June 2009

Keywords:
Filtration
Monolith
Electrical capacitance tomography
Periodic operation
Liquid saturation

ABSTRACT

The filtration of gas/(kaolin-kerosene) suspension flows in monolith reactors was monitored using electrical capacitance tomography. Two flow modulation modes (fast and semi-fast) were compared to constant-throughput feeds of the suspension in a quest for strategies for the reduction of fines accumulation. The effects of initial distribution of liquid suspension and superficial velocities, and base-pulse time splitting of flow modulation were found to affect both the structure of deposition and the amount of deposited fines. One major finding concerned dampening of liquid hydrodynamic waves generated in flow modulation which could severely limit implementation of self-cleaning fast-modulation strategies of monolith reactors subject to filtration of suspensions.

1. Introduction

In recent years, monolith reactors have been under the scrutiny of many research groups in the quest of alternatives to the well-trodden slurry or trickle-bed reactors. Several advantages such as low pressure drop, high mass transfer rate and short diffusion paths, low backmixing, and ease of scale-up are claimed to be achievable by virtue of the repetitive and regular geometry of parallel channels in monolith blocks (Nijhuis et al., 2001; Roy et al., 2004; Boger et al., 2004). In the context of upgrading heavy gasoil from tar sands, incentives to implement monolithic hydrotreating reactors stems from a yet-to-be-proven capability to replace trickle-bed hydrotreaters in which deposition of fines is known to shorten operational lifetime of the catalyst bed. Tar sands are complex multiphase systems which besides bitumen and sand, also contain fines comprised of silt, very fine quartz and clay minerals. A tiny fraction of these fines is not totally stoppable by the upstream filters and carry over in the heavy gasoil fraction to the hydrotreaters. Their accumulation causes the pressure to rise leading to frequent hydrotreater shutdowns for catalyst replacements; often well before exhaustion of the catalyst activity (Gray et al., 2002). Fines deposition occasions increases in energy consumption, operational costs and maintenance work. Current efforts strive to devise new solutions to improve reactor operational life by minimizing deposition of fines in the hydrotreating unit (Dehkissia et al., 2008).

A great deal of researchers have contributed to clarify the benefits of periodic operation on the performance of trickle beds in terms of hot spot prevention or mass transfer enhancement (Silveston and Hanika, 2002; Boelhouwer et al., 2002; Dudukovic et al., 2002). In periodic operation, a constant flow of one phase (either gas or liquid) encounters another phase with a variable flow oscillating periodically between two limits, i.e., base and pulse. These latter are characterized by base and pulse times (t_b, t_p) and velocities (U_{lb}, U_{lp}), split ratio ($R = t_p/(t_p + t_b)$), and barycentric velocity $U_L = (t_p \times U_{lp} + t_b \times U_{lb})/(t_p + t_b)$ of constant-throughput "isoflow" mode to which periodic operation is compared to.

The assumption that straight channels as in monoliths could reduce the extent of deposition was tested where the filtration performances of 1-mm channel monolith and trickle flow reactors were compared (Hamidipour et al., 2007a). Pressure drops, an order of magnitude less in monoliths, were found as well as ca. 50% less deposition for similar collector area and operating conditions as in trickle beds. Such reduction in specific deposits was not spectacular suggesting that replacement of trickle beds with monoliths remains to be demonstrated. A legitimate extension to further lower the extent of deposition in monoliths would be the testing of flow modulation strategies as some of these strategies have been shown to decrease the amount of deposits in trickle-bed reactors (Hamidipour et al., 2007b). Flow modulation could help detaching, re-entraining and clearing deposits owing to the imposed waves which, while traveling streamwise, could eliminate additional amounts of deposits, otherwise captured inside the bed had it been operated at constant throughput.

Due to the opaque nature of monoliths, wall observations are helpless to clarify the deposition mechanisms inside the channels. Therefore, measuring techniques, ideally non-invasive and able to interrogate the reactor interior should be applied to image the evolution of deposits inside the monolith blocks. Electrical capacitance

* Corresponding author. Tel.: +1 418 656 3566; fax: +1 418 656 5993.
E-mail address: faical.larachi@gch.ulaval.ca (F. Larachi).

0009-2509/$ - see front matter
doi:10.1016/j.ces.2009.06.040

tomography (ECT) is a method suitable for measuring electrically non-conducting organic liquids such as kerosene mixed with kaolin fines, which is used in ambient filtration tests as a proxy to heavy gasoil suspensions. Though the ECT spatial resolution, ca. 5% vessel diameter, will not allow resolving single-channel plugging dynamics, its high temporal resolution makes it appropriate to capture time-of-flight transients of flow modulation in the bed (Mewes et al., 1999).

The aim of the present work is to interrogate with ECT the inception and evolution of deposition inside monolith reactors. In addition, different suspension flow modulations were tested with a goal to reduce the amount of deposit in monoliths, and their performances were compared to the corresponding isoflow (barycentric) velocity conditions in terms of pressure drop and specific deposit build-up.

2. Experimental

Single-pass suspension flow tests were performed in a 5.7-cm-ID Plexiglas column hosting four identical 15-cm-high and 5-cm diameter monolith blocks having 1-mm square channel opening and 0.2 mm thick walls. The blocks were juxtaposed to ensure channel alignment by means of metal wire guides and tightened to provide seamless 60 cm long channels using Teflon bands and Plexiglas rings. Kaolin-kerosene suspension and air were the test fluids in co-current down-flow. Addition of kaolin to kerosene without treatment resulted in suspensions of large-size fines. This was avoided by sonicating mildly concentrated kaolin slurries before addition to kerosene. Mean fine diameters ca. 8 μm were typical with 1 g/L suspensions. Prior to experiments, the bed was immersed in kerosene to ensure full wetting. The suspension was stirred in a feed tank, pumped to the column top and distributed through a spray nozzle. Air was fed through several small holes to prevent preferential

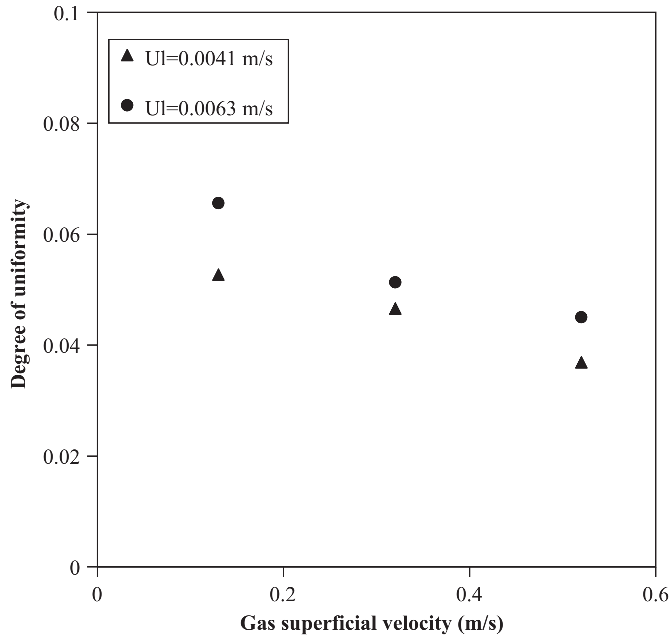

Fig. 2. Effect of gas and liquid superficial velocities on the distribution of liquid across the monolith bed image at $z = 10$ cm.

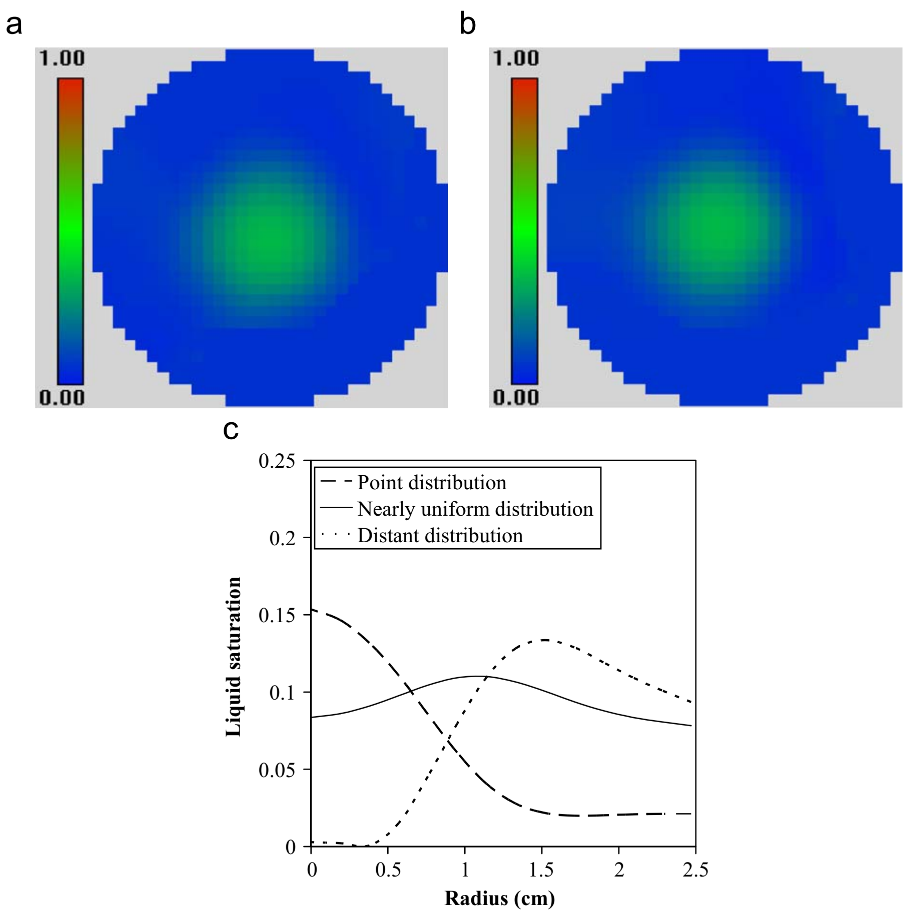

Fig. 1. (a) and (b) ECT normalized permittivity images at $z = 10$ cm and 50 cm deep in the bed with centered point distribution of liquid 3 cm above monolith, (c) radial distribution of liquid saturation across monolith with centered point, distant and nearly uniform distributions, image at $z = 10$ cm, $U_g = 0.13$ m/s, $U_l = 4$ mm/s.