Chemical Engineering Science 62 (2007) 6002–6014

Chemical Engineering Science

www.elsevier.com/locate/ces

Modulation of liquid holdup along a trickle bed reactor with periodic operation

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Received 16 April 2006; received in revised form 8 May 2007; accepted 17 June 2007
Available online 27 June 2007

Abstract

Temporal variations of the liquid holdup in a mini-pilot scale trickle bed reactor cold-mockup, induced by an ON–OFF liquid flow modulation strategy of operation, are explored at different axial positions. The reactor is packed with porous beads of γ-Al_2O_3 and the liquid holdup is approximately estimated with a conductimetric technique, using probes that mimic the packing. The effects of the liquid and gas superficial velocities, the bed depth and the cycling parameters, cycle period and split, on the liquid holdup modulation are examined for a wide range of conditions. For slow and intermediate cycle periods, the liquid holdup time dependence observed during the dry period is represented by an exponential function. The characteristic value of the decay is correlated to the examined variables. The correlation allows reconstruction of the liquid holdup time dependence along the column.

Keywords: Trickle-bed reactors; Liquid flow modulation; Liquid holdup profiles; Periodic operation; Hydrodynamics

1. Introduction

In the last decade, the improvements in terms of production capacity and/or conversion that can be attained in trickle-bed reactor (TBR) performance by modulating the fluid flow rates have been highlighted, particularly for processes limited by the gas reactant mass transfer. Significant enhancements have been achieved employing relatively long cycle periods (Lange et al., 1994; Castellari and Haure, 1995; Khadilkar et al., 1999), in which the whole reactor works for some time in the wet cycle and some time in the dry cycle. In addition, successful results have also been obtained when working with intermediate to short cycle periods (Banchero et al., 2004; Muzen et al., 2005).

A thorough understanding of the underlying hydrodynamics plays an important role in the possibility of properly describing the phenomena taking place in a TBR under liquid flow modulation. Since many key design parameters are strongly affected by the liquid holdup and the liquid distribution over the particles, the impact of liquid flow modulation needs to be addressed in detail. So far, only a few contributions accounting for the influence of liquid flow modulation on the hydrodynamics of a TBR have been reported. Furthermore, the effect of non-steady state operation on liquid hold up, mass transfer coefficients and wetting efficiency has been scarcely investigated (Boelhouwer, 2001; Borremans et al., 2004; Giakoumakis et al., 2005). Only very recently, Trivizadakis et al. (2006) studied the imposed pulse characteristics employing porous spherical and cylindrical extrudates. These authors found that spherical packings hold significant advantages over cylindrical extrudates of comparable size. Besides, Aydin et al. (2006) assessed the effect of temperature and pressure on the slow-mode induced pulsing characteristics.

Results presented in the literature for liquid holdup time variations under periodic operation are still limited and mostly carried out for non-porous packings. Besides, the influence of the cycling parameters has been examined only within a narrow range. To further understand the hydrodynamic behavior of TBRs under liquid flow modulation, experiments in a broader range of conditions using porous packings are still required

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0009-2509/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ces.2007.06.027

in order to select assumptions and design parameters for appropriately simulating reactor performance when a cycling strategy is used (Lange et al., 2004).

In the present contribution, a conductimetric technique is employed to obtain the time evolution of the liquid holdup in cycling experiments with a non-reacting system, consisting of a packed bed of inert γ-Al_2O_3 spherical particles, through which air and water flow cocurrently downwards. Instantaneous liquid holdups at several column depths are estimated without affecting the flow, by using probes that mimic the packing. Steady-state liquid holdups are also measured by residence time distribution experiments to calibrate the probes response. Then, the influences of gas and liquid velocities, bed depth and cycling parameters on the liquid holdup temporal modulation are addressed. For slow and intermediate cycle periods, the liquid holdup time dependence during the dry period is fitted to an exponential function. The characteristic value of the exponential decay is correlated to the examined operating variables, to reconstruct the liquid holdup time variation along the column under periodic operation.

2. Experimental

A schematic diagram of the experimental installation is shown in Fig. 1. The setup basically consists in an acrylic column of 7 cm inner diameter and a total height of 220 cm, provided with appropriate fluid feeding and regulating systems. The actual packed bed length is 150 cm. Some characteristics of the packing are given in Table 1. The tube to particle ratio is 22.6, well above the limit suggested in the literature to avoid wall effects; thus, channeling can be assumed negligible.

The packing is supported, at the bottom of the column, by a rigid stainless steel screen. Beneath the screen, there is a gas–liquid separator that vents the gas and returns the liquid to a reservoir. The liquid enters the column at the top, through a liquid distributor made in acrylic. The distributor has 18 holes of 1 mm diameter. Gas is provided from a compressor and goes into the column at the top, above the liquid distributor.

The liquid is fed from a reservoir with a peristaltic pump controlled by a rotor velocity regulator, which is commanded by a programmable logic controller (PLC). Gas flow rate is

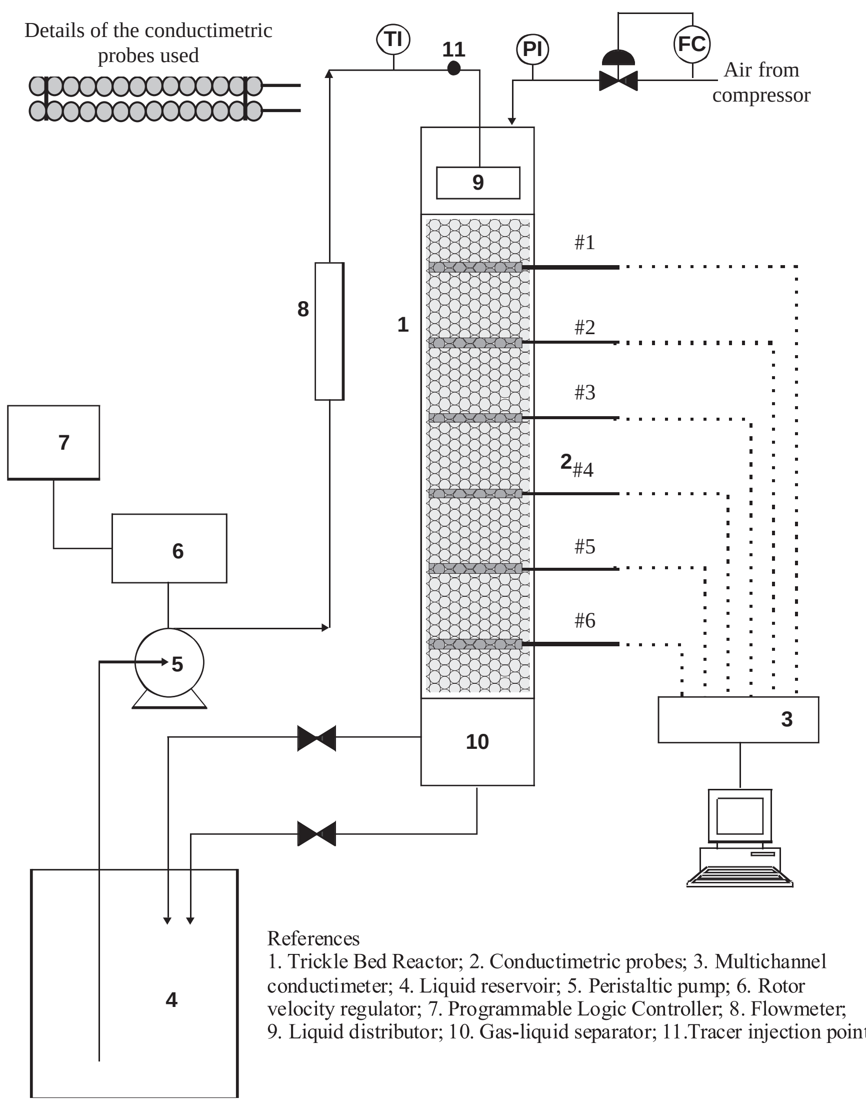

Fig. 1. Schematic diagram of the experimental setup.