

Review

Bubble columns operated under industrially relevant conditions – Current understanding of design parameters



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ABSTRACT

Despite the fact that bubble columns are widely established within the process industry as multiphase reactors and gas–liquid contactors, common research has been focused on the description of bubble column hydrodynamics under atmospheric conditions. Industrial production is usually conducted at pressures above atmospheric and temperatures above ambient in processes primarily involving the use of organic solvents. Because hydrodynamic parameters such as gas holdup and backmixing determine the necessary reactor design and impact reactor performance, detailed knowledge of these variables is crucial for optimal design and operation of bubble column reactors. The purpose of this article is to give an overview of research studies that deal with bubble column hydrodynamics at elevated pressures. A recommendation for further research concerning this topic is provided as well.

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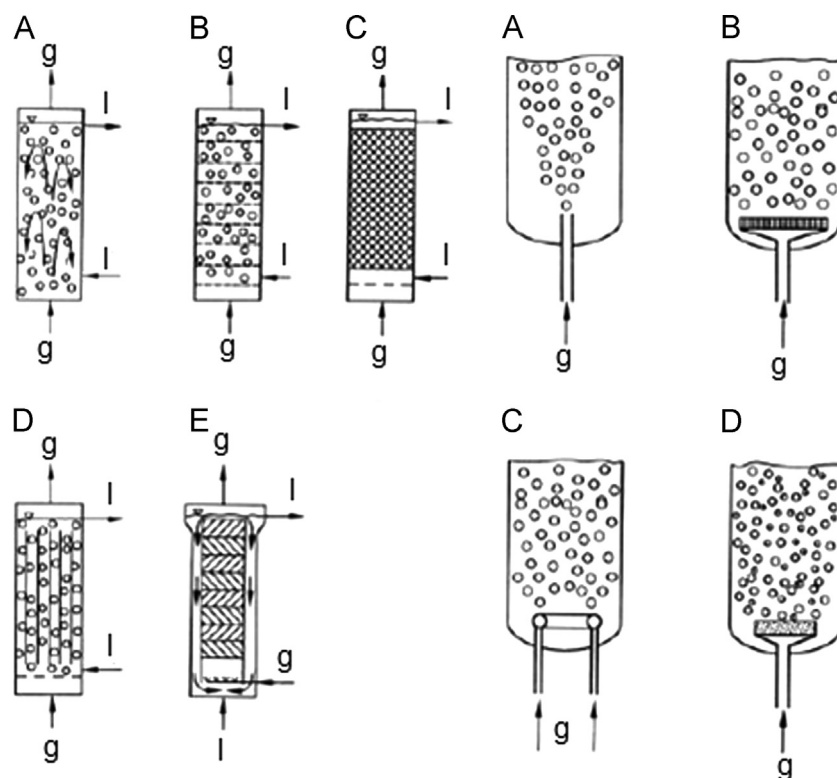


Fig. 1. Left: examples of bubble column designs (A) empty, (B) cascaded, (C) packed, (D) multishaft, and (E) equipped with static mixers. Right: examples of gas spargers (A) simple tube, (B) perforated plate, (C) perforated ring, and (D) porous plate; figure taken from Deen et al. (2000).

1. Introduction

Bubble columns are widely employed within the chemical industry as gas–liquid contactors and multiphase reactors (Schumpe et al., 1979; Dudukovic et al., 1999; Weber, 2002). Examples of applications of this reactor type include oxidations (Weber, 2002; Sifniades et al., 2000; Sheehan, 2000; Oppenheim and Dickerson, 2000), hydrogenations (Dadyburjor et al., 2000), fermentations (Junker, 2000; Merchuk et al., 1994) and the production of synthetic fuels (Han and Chang, 2000).

One of the main features of bubble column operation is that gas and liquid or suspended solid phases are brought in contact without the need for additional mechanical stirring equipment, making bubble column design and operation appear easier than that of other gas–liquid reactors (Deen et al., 2000; Deckwer, 1985; Gerstenberg, 1979; Mersmann, 1989). The gas distributor is usually located at the bottom of the column, while the liquid phase can either be distributed co-currently or counter-currently with respect to the flow direction of the gas phase. Semi-batch operation without any liquid flow is also possible. Gas distribution itself takes place via perforated plate spargers, ring type distributors, perforated pipes, porous plates and jet nozzles in various geometrical configurations suited to the needs of a specific process (Kulkarni and Joshi, 2011a, 2011b). Some examples of bubble column and sparger designs according to Deen et al. (2000) can be seen in Fig. 1. To make things more complicated, bubble columns are often equipped with internal heat exchangers (vertical or horizontal) to control the reactor temperature which in addition to other internals influence the hydrodynamics of the reactor.

As hydrodynamic parameters such as gas holdup and liquid backmixing affect not only the overall design of a bubble column reactor but also important variables such as yield and selectivity of a given chemical reaction (Shah et al., 1978; Baldyga et al., 1997; Levenspiel and Bischoff, 1959), a brief overview of some important definitions encountered when dealing with bubble columns would

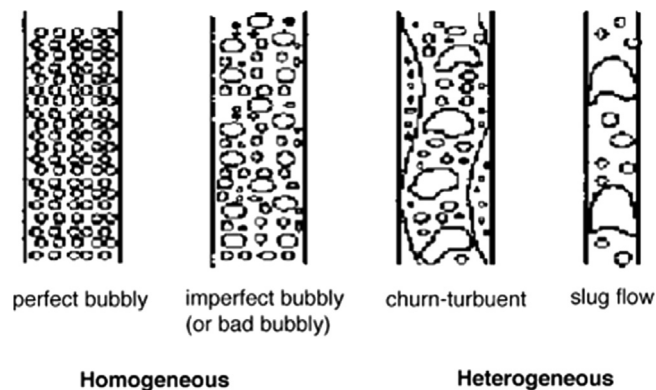


Fig. 2. The most common flow regimes encountered in bubble columns (Reilly et al., 1986).

seem appropriate. A more detailed introduction to the characteristics of bubble columns may be found in Kantarci et al. (2005).

According to Deckwer (1985), the hydrodynamic flow regimes of a bubble column are divided into four main groups (Fig. 2): the homogeneous regime (equal bubble sizes), the heterogeneous regime preceded by a transition regime (wide bubble size distribution) and the slug-flow regime (bubbles and slugs up to the column diameter in size).

The prevailing flow regime is dependent on superficial gas velocity, column diameter, the physical properties of the components, the type of gas distribution, integrated internals, and the pressure and temperature at which the reactor is operated (Ruzicka et al., 2001a, 2001b; Vial et al., 2001). Homogeneous flow regime, however, is characterized by relatively small, uniformly sized bubbles, and occurs at low superficial gas velocities. Heterogeneous flow can be described by the existence of a wider bubble size distribution due to the coalescence and breakup of

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