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Bubble column reactors for high pressures and high temperatures operation

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ABSTRACT

Bubble column reactors are multiphase contactors based on the dispersion of a gas phase in the form of bubbles inside a cylindrical vessel where a liquid or a suspension circulates. Those reactors present many advantages such as good heat and mass transfer rates, no moving parts, compactness, easy operating and low maintenance and operating costs. Their main drawback is the significant backmixing which can affect selectivity and conversion of reaction products. They have gained particular attention in the field of wastewater treatment for Wet Air Oxidation (WAO) processes application. Those processes are operated at high pressures (up to 30 MPa) and temperatures (up to 573 K). In order to efficiently operate those processes, conversion, heat and mass transfer must be optimised. Those parameters depend themselves on operating conditions such as pressure, temperature, superficial gas and liquid velocities and on design parameters such as sparger and column design. This review is aimed to find the relevant parameters for operating bubble column at high pressures and temperatures in continuous mode. The main mechanisms governing the bubble column will be described. The influence of the different parameters on gas holdup, mass transfer properties and on liquid axial dispersion coefficient will be extensively studied.

Contents

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1. Introduction

Bubble column reactors are multiphase gas–liquid–solid contactors in which the dispersed phase is a gas and the continuous phase is a liquid or a suspension. The gas phase is dispersed into the liquid or suspension in the form of bubbles by means of a gas sparger generally placed at the bottom of the column. The column can be designed to work in semi-batch mode (batch for liquid) or in continuous mode. Few studies deal with co-current bubble columns (Bićń et al., 2001; Chaumat et al., 2005; Choi and Wiesmann, 2004; De Bruijn et al., 1988; Fukuma et al., 1987; Gopal and Sharma, 1983; Holcombe et al., 1983; Ishibashi et al., 2001; Jin et al., 2007b; Kumar et al., 2012a,b; Majumder et al., 2006; Muroyama et al., 2013; Onozaki et al., 2000; Pjontek et al., 2014; Pohorecki et al., 1999; Pohorecki et al., 2001; Sangnimnuan et al., 1984; Shawaqfeh, 2003; Simonnet et al., 2007; Tarmy et al., 1984; Voyer and Miller, 1968; Yang and Fan, 2003) and fewer with counter-current bubble columns (Bićń et al., 2001; Hikita et al., 1981; Jin et al., 2010; Maalej et al., 2003; Shah et al., 2012; Smith et al., 1996; Stegeman et al., 1996).

Bubble column reactors are generally used as reactors in chemical, biochemical, petroleum and metallurgical industries. In particular, among the different types of chemical reactions, oxidation, chlorination, alkylation, polymerisation, esterification (see Stacy et al., 2014 for a recent application) and hydrogenation can be implemented in bubble columns. They can also be used to operate other processes such as gas conversion to produce fuels or fermentation and biological wastewater treatment in the field of biochemical processes. The Fischer–Tropsch synthesis, which is the coal liquefaction to produce fuels, is carried on bubble columns and is widely studied in the literature (Behkish et al., 2002; Deckwer et al., 1980; Gandhi et al., 1999; Hulet et al., 2009; Krishna and Sie, 2000).

Among the different processes that can be operated in bubble columns, Wet Air Oxidation (WAO) has received particular interest in the field of wastewater treatment (Boutin et al., 2011; Debellefontaine et al., 1996; García-Molina et al., 2007; Kolaczkowski et al., 1999; Lefèvre, 2010; Lefèvre et al., 2011). This process is aimed to treat wastewater (organic effluents, sludge from wastewater treatment plant...) by putting it in contact with an oxidizer (such as oxygen). The process can be catalysed or not. WAO processes are operated to work at high pressures and high temperatures. Pressure conditions are typically set between 2 and 18 MPa for catalysed processes and between 2 and 30 MPa for non-catalyzed processes. Temperature conditions are generally set between 373 and 593 K. Working at those conditions is necessary to increase partial pressure and solubility of oxygen in the liquid phase and increase the kinetic rate of the oxidation reaction. Those WAO processes are typically operated in bubble columns as it provides a high liquid holdup necessary to achieve high mass transfer efficiency for slow reactions.

Several parameters influence the operating of bubble columns. Among them, it can be distinguished between operating parameters such as gas–liquid system studied, pressure, temperature, gas and liquid superficial velocities, operating mode (semi-batch, co-current or counter-current) and design parameters: column height and diameter and sparger design. Many studies focus on the effect of several of these parameters on the performance of the bubble column in terms of heat transfer, mass transfer (Table 1), gas holdup (Table 1) or bubble diameter (Table 1) and on the flow regimes (Chilekar, 2007, 2010; Cui, 2005; Gourich et al., 2006; Grover et al., 1986; Hashemi et al., 2009; Jin et al., 2007b; Kang et al., 2000; Kemoun et al., 2001; Krishna et al., 1994, 2000; Krishna et al., 1991; Letzel et al., 1997; Lin et al., 2001; Passos et al., 2015; Reilly et al., 1994; Ruzicka et al., 2001; Şal et al., 2013; Shaikh and Al-Dahhan, 2005; Tarmy et al., 1984; Thorat and Joshi, 2004; Vial