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Characterisation of a high concentration ionic bubble column using electrical resistance tomography

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ABSTRACT

Attentions has been given to ionic liquids as an alternative physical solvent for carbon dioxide (CO_2) absorption because of their potential for gas selectivity, absorption capacity and low desorption energy by tailoring the molecules. Ionic liquid normally have a high viscosity, which influences the performance of absorption processes, and therefore, efficiency. This study investigates the hydrodynamics of ionic liquids in a two-phase gas–liquid flow by determination of the bubble formation, distribution of gas and bubble velocity profiles. A dual plane electrical resistance tomography (ERT) system and an optical imaging device were applied to a bubble column reactor of 50 mm internal diameter for the study. The model ionic liquids were aqueous solutions of sodium chloride (NaCl) with conductivity adjusted by altering the concentration of NaCl. Gas holdup has been estimated by analyses of conductivity data obtained from ERT by application of Maxwell's relationship which reveals significant increase in gas holdup as ionic concentration increases and is in good agreement with other studies.

1. Introduction

Bubble column reactors are widely used as multiphase gas–liquid contacting devices. Some of its advantages include the ease by which they can be operated and controlled, low operating cost and high energy efficiency. Bubble column reactors have several industrial applications which are often applied to determine the hydrodynamics of bubble swarm characters such as gas holdup; bubble rise velocity; flow regimes identification or patterns and characteristics of flow structure occurring in various gas/liquid reactions. Several types of bubble column reactors commonly used today are shown in Fig. 1. They include: (a) simple bubble column; (b) cascade bubble column with sieve tray; (c) packed bubble column; (d) multi-shaft bubble column; and (e) bubble column with static mixers. The study [1] of bubble swarm characters are important for the determination of how they affect the specific gas–liquid interfacial area, residence time distribution, mass transfer rates and rates of reactions in most chemical processes. Accurate estimation of bubble size distribution is very pertinent in determination of hydrodynamics which has been met by the technique of Dynamic Gas Disengagement (DGD), first introduced by Sriram and Mann [2] based on the disengagement rates of gas holdup and level of gas–liquid dispersion after the gas flow to the bubble column was shut off. The DGD technique is widely adopted in the study of gas holdup, bubble size distribution and bubble rise velocity profiles as shown by Wang et al. [3], pp. 459–464). Knowledge of the behaviour of such systems is imperative in improving the process efficiency of its industrial process applications which by nature are very complex [4]. Bubble column reactors are commonly applied in chemical processes involving several reactions such as oxidation, chlorination, polymerisation and hydrogenation. They are extensively used in the manufacture of synthetic fuels by gas conversion processes and in biochemical processes such as fermentation and biological wastewater treatment [5,6]. A very broad chemical application of bubble column is the Fischer–Tropsch process which is the indirect coal liquefaction process to produce transportation fuels, methanol synthesis and manufacture of other synthetic fuels which are environmentally friendly over petroleum derived fuels [7]. Further industrial applications of bubble column reactors include catalytic reactions, coal liquefaction and bio reactions.

Liquids which are salts below 100 °C are generally classified as ionic liquids i.e. solvents which are often fluids at room temperature while consisting entirely of ionic species. Ionic liquids are generally made of ions and short lived ion-pairs which are sometimes referred to as ionic melts, liquid electrolytes, ionic

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fluids, fused salts etc. Common examples of ionic liquids include 1,3-dialkylimidazolium chloride, ethyl ammonium nitrate, and 1-ethyl-3-methylimidazolium. Studies by Freemantle [9] reveal the primary driving forces behind various research works into ionic liquids which are the perceived benefits of replacing traditional industrial solvents most of which are volatile organic compounds with non-volatile ionic liquids. This would enhance reduction in the emission of volatile organic compounds which constitutes major sources of environmental pollution. Room temperature ionic liquids possess several advantages in an industrially relevant catalytic process over other solvents largely due to the lack of detectable vapour pressure, and thereby do not contribute to the volatile organic compound emissions into the atmosphere as described by Seddon [10].

There are presently very few industrial applications of these classes of liquids which include inorganic; organic and catalytic synthesis; biochemistry; electrochemistry; analytical chemistry; chemical engineering; and material sciences. Some specific applications include cellulose processing; dispersants; gas handling; gas treatment; nuclear industry; solar energy; high purity organometallic compounds; food and bio-products; waste recycling; batteries etc. Recent and ongoing researches on ionic liquids (this inclusive) are focused on its suitability as alternative solvents for carbon dioxide (CO_2) absorption due to their low vapour pressures [11]. Ionic liquid properties such as thermal stability, solubility of carbon dioxide and selectivity over nitrogen have been investigated by Styring et al. [13] and Tand et al. [12]; results obtained from their studies show high CO_2 absorption capacity, selectivity and low solvent loss which potentially make polymers of ionic liquids suitable for carbon dioxide absorption over amine based fluids such as monoethanolamine (MEA) and diethanolamine (DEA).

It is worthy to note that the selection of a suitable solvent for CO_2 absorption is crucial for economic viability of any process [14]. This arises due to high cost of ionic liquids when large scale industrial applications are considered. The thermodynamics and kinetics of reactions carried out in ionic liquids are markedly different from those in the convectional molecular solvents, making the chemistry of most ionic liquids unpredictable at our current knowledge base. This is in fact, the major reason for this study. The limitation in the application of ionic liquids can largely be attributed to the limited understanding of the classical, physical and thermodynamic properties associated with ionic liquids [15].

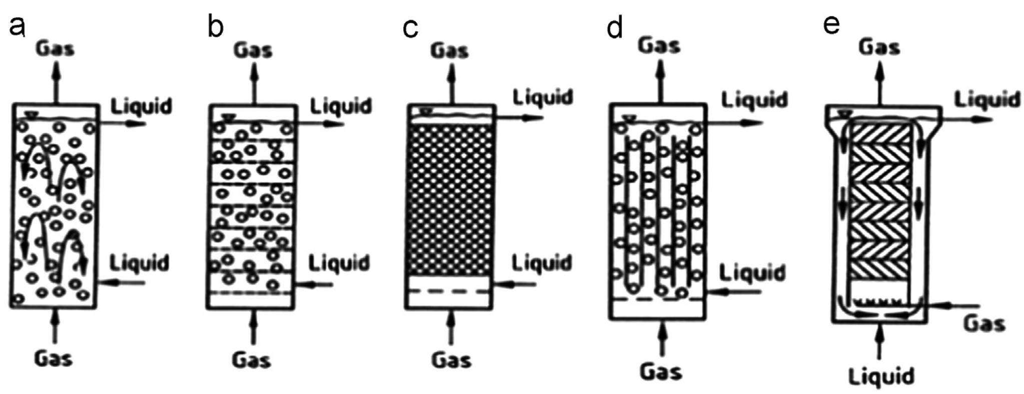

Fig. 1. Types of bubble column reactors [8].

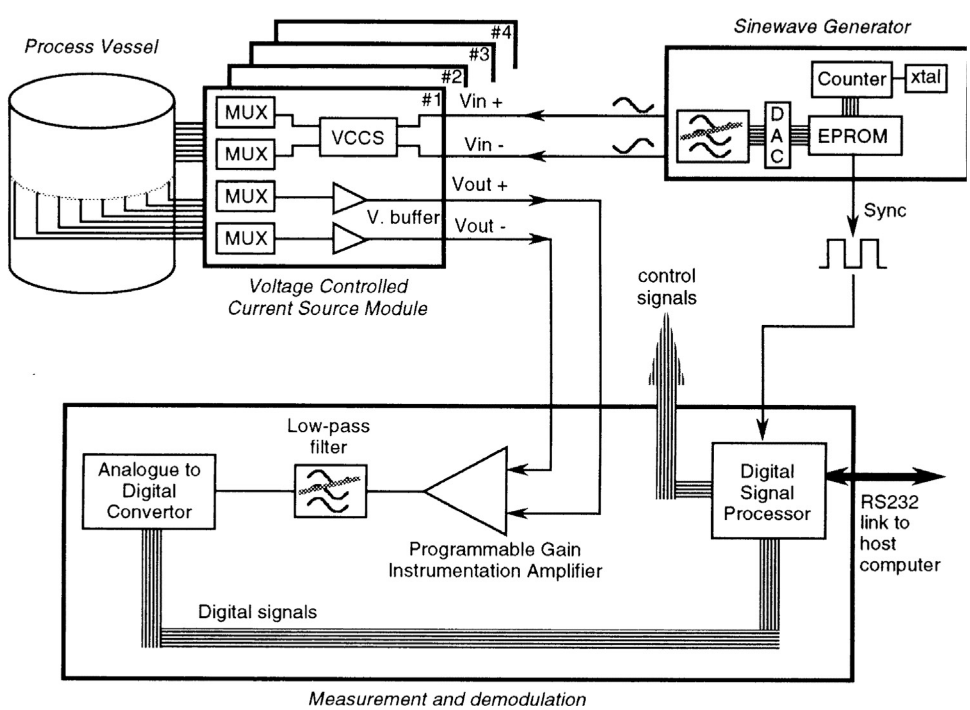

Fig. 2. An electrical resistance tomography data acquisition system [17].