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Multi-stage fluidized bed column: Hydrodynamic study

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Abstract

In our recent work we carried out mass transfer study on the multi-stage fluidized bed ion exchanger column with solids and liquid flowing in the counter current directions and demonstrated improved separation efficiency of dissolved anions from waste water in comparison to that achieved in a fixed bed operation. In this study, we report the results pertaining to hydrodynamic study with a view to ascertaining the type of fluidization prevailing on the column's stage and the operating range of liquid and solid flow rates for the steady and stable operation of the column without loading or flooding with excess solid or water flow rates. Residence time distribution (RTD) study was carried out to investigate the extent of mixing on the stages. In addition, the experimental measurements for pressure-drops were made over a wide range of operating conditions including number of stages, height of the downspout on every stage, and the liquid and solid flow rates. Based on the data, empirical correlations were developed using scale-up analysis for predicting pressure-drop, bed porosity and average bed height during cross-flow fluidization apparently prevalent on the stage. The results in this study assume significance from the perspective of design and stable operation of staged fluidized bed ion exchangers.

Keywords: Ion exchange; Fluidization; Dimensionless analysis; Hydrodynamics; Bed porosity

1. Introduction

Fixed bed ion exchangers are commonly employed in treating waste water for dissolved anionic or cationic impurities. The treatment in fixed bed exchanger is essentially a batch operation, as it requires periodic regeneration following saturation of the ion exchanger resins. The continuous operation of ion exchangers may be achieved in staged column with water flowing in the upward direction through the mesh of various stages and the fluidized solid particles flowing across the stage and then onto the next stage through a downspout tube fitted in the column. Literature is replete to some extent with studies carried out on the multi-staged fluidized bed contactor applied in gas–solid applications [1–3]. In these studies the focus is on the application of the stage-wise operation in continuous drying or cooling of the solid particles using air as the drying or cooling agent. Some of these studies also focus on the types of flow patterns prevalent in the gas–solid fluidized beds and the development of correlations for estimating gas to particle heat and mass transfer coefficients. Commercial reactors for calcinations based on multi-staging are also in operation [4]. On the other hand, the reported literature for the stage-wise operation of the liquid–solid contactors for ion exchange applications is scant. Although there are commercial units since late 1960s utilizing the principles of stage-wise operation in water softening and mineral processing, the technology is patented and the published data are inadequately informative [5,6]. A list of some of the commercial units based on different types of liquid–solid contactor may be obtained in Ref. [7]. In some of the early works, Dodds et al. [8] have also studied the operation of the stage-wise solid–liquid contactor specifically designed for the ion exchange treatment, albeit in a semi-continuous operation in which resins were periodically transferred to the lower stage, except for the top plate on which resins were continuously fed. The water to be treated was fed to the bottom of the contactor. The contactor consisted of a series of stages separated by pairs of especially designed horizontal perforated plates without downcomer to insure no particle-drainage occurred under no-flow condition of water. Gomez-Vaillard and Kershenbaum [9] later extended the study to investigate the effect of operating conditions on the performance of the reactor.

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In our recent work, we presented the data pertaining to mass transfer studies carried out on a five-stage Perspex made column and showed that 90% reduction in the dissolved solute concentrations may be achieved relative to the inlet concentration during a typical continuous operation [10]. The experiments were carried out over varying water and resin flow rates and inlet solute concentrations. The results showed a gradual leveling off in the solutes removal efficiency with increasing number of stages; a mass transfer effect which is a characteristic of stage-wise unit operations. In this work we present the results pertaining to hydrodynamic study with a view to determining the operating range of water and resin flow rates for the smooth and stable operation of the multi-staged column, without flooding of the stages with water or loading of the stages with resins corresponding to two extreme scenarios of the operation. The study also includes ascertaining type of fluidization and extent of mixing (or channeling) on various stages of the column by determining residence time distribution (RTD) of flowing water through voids between the resin solids. The RTD study was carried out over a wide range of operating conditions including water and solid flow rates, number of stages and stage heights. Finally, using scale-up analysis various dimensionless parameters are identified and correlations developed for predicting pressure-drop, bed porosity and average bed height as functions of the operating variables during cross-flow fluidization of the solids by water. In the following section we have explained that although the overall operation of the multi-staged fluidized bed column may be considered to be counter current, there is apparently cross-fluidization of the solids on stages, with water flowing in the upward direction and the fluidized solid resins flowing horizontally across the stage. We would like to point out that in recent times computational fluid dynamics (CFD) has been considerably used in addressing a wide range of flow scenarios including those existing in bubble columns, fluidized bed reactors and sieve trays [11–13]. Few experimental studies are also reported for re-circulating liquid–solid systems [14,15]. However, to the best of the authors' knowledge no study using either CFD or other technique has been reported concerning hydrodynamics for the staged ion exchange column, with cross-flow fluidization of the solid particles by water.

2. Multi-staged fluidized bed column

The configuration of the staged liquid–solid ion exchange column is similar to that of the sieve trays distillation column used for vapour–liquid contacts. Fig. 1 is the schematic of the multi-staged fluidized bed ion exchange column fabricated and used in this study. The Perspex made column (500 mm H × 100 mm i.d.) essentially consisted of five stages (65 mm height per stage) assembled together with flange joints. A brass made mesh with openings smaller than the particle size was fitted onto an aluminium ring sandwiched between every pair of adjoining flanges. The fluidized solid resin particles moved across the stage on to the next stage through a downcomer, as water flowed upward through the mesh openings. Fig. 2 is the schematic of the single stage configuration. As shown, the downcomer consists of two concentric tubes, assembled with the help of the rack and pinion arrangement. The arrangement allows the adjustment of the stage height by moving two tubes vertically up or down independently. Thus the bed heights on two adjacent stages could be adjusted independently without stopping or interrupting the operation. In the existing arrangement, the resin bed heights could be varied between 2 and 20 mm. In principal, the required bed height is determined from the mass transfer consideration and should be equal to mass transfer zone (MTZ). Counter current operation of solid–water flow permits achieving the required mass transfer rate within a small height [10]. In the existing configuration, provisions were made on every stage for pressure-drop measurements across the stage height with the help of a manometer. Fresh resins were fed from the top using conveyor belt. The solid flow rate was controlled by adjusting

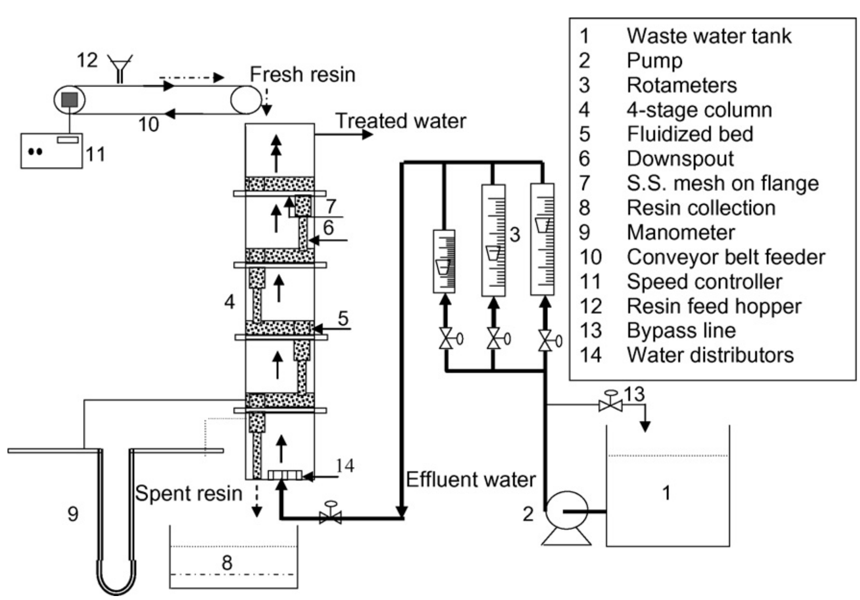

Fig. 1. Schematic diagram of multi-stage fluidized bed column.