Journal of the Taiwan Institute of Chemical Engineers 47 (2015) 171–176

Contents lists available at ScienceDirect

Journal of the Taiwan Institute of Chemical Engineers

journal homepage: www.elsevier.com/locate/jtice

Investigation of the performance of a batch air spouting bed in conducting ion exchange reactions involving heavy metal removal

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ARTICLE INFO

Article history:
Received 1 June 2013
Received in revised form 26 September 2014
Accepted 5 October 2014
Available online 13 November 2014

Keywords:
Ion exchange
Zeolites
Heavy metals
Kinetics
Gas spouted bed
Mass transfer

ABSTRACT

Spouted beds provide a means of good hydrodynamic conditions and circulation of solid particles. The spouting technique has been applied in many industrial processes, such as drying of granular materials, blending of polymer chips, coating of tablets, pyrolysis, gasification, and granulation of fertilizers. The aim of the present study is to examine the performance of a batch conical air spouting vessel for conducting ion exchange reactions involving heavy metal removal. The rate of ion exchange reaction was expressed in terms of volumetric mass transfer coefficient (*K*). The effect of various parameters such as type of heavy metal ion (Ni^{2+}, Pb^{2+}), superficial air velocity, and initial heavy metal concentration has been investigated. It has been found that volumetric mass transfer coefficient increases as air superficial velocity increases. Mass transfer correlations were obtained using dimensional analysis of the present mass transfer data. The importance of these mass transfer correlations in the design and operation of air spouting vessels used for conducting diffusion-controlled reactions was highlighted.

1. Introduction

Fluidization was been widely accepted as a solid–fluid contacting technique.

Relatively fine particles are desirable for good quality fluidization operations [1]. The spouted bed technique is a variant of fluidization. Solid materials that are too coarse and uniform in size to fluidize well may be agitated in a spouted bed.

Under conditions of spouting, the bed consists of two distinct zones: the very dilute phase central core called the spout, and the surrounding dense phase annular solids called the annulus [2]. The gas enters the bed through a small opening at the central orifice of the distributer plate or to the apex of a conical or flat base causing the formation of a central spout in which the particles move upwards in a dilute phase [3]. The annular space between the spout and the vessel wall contains a packed bed of particles, moving slowly downwards and radially inwards. The gas flares out into the annulus as it travels upwards, rapidly at first and then more gradually, but the gas velocity in the annulus remains below the velocity necessary to fluidize the annular solids as illustrated in Fig. 1a and b [4]. Conical spouted beds have the properties of conventional spouted beds (cylindrical conical base), while also allowing for strong gas–solid contact since they operate stably in a wide range of gas flow rates [5].

Analogous to conventional fluidized beds, spouted beds are well known for their good mixing of the solid phase and also for their intensive heat and mass transfer characteristics between the fluid phase (gas) and the solid phase yielding nearly isothermal conditions [6]. The special flow structure of a spouted bed is characterized by a simple apparatus construction. The main difference of spouted beds in comparison with conventional fluidized beds is the variable cross-section area of the apparatus as a function of the apparatus height [7]. Air sparging is known to be more economic than the mechanical stirring used in traditional fixed and fluidized bed [8].

The spouted bed has proved to be of interest for a variety of processes, such as drying [9], cooling, coating and blending of granular materials [10], granulation of fertilizer, carbonization of coal, pyrolysis of shale [11], polymerization of benzyl alcohol on acidic catalysts, and in gasification [12]. Despite the high mixing efficiency of spouted beds, little work has been done to use them for heavy metal removal from wastewater. The aim of the present work is to explore the possibility of using batch air sparged spouted

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http://dx.doi.org/10.1016/j.jtice.2014.10.003
1876-1070/

Nomenclature

Symbols

A	surface area of resin (cm^2)
a_1	constant (–)
C	concentration of heavy metal at time (t) (ppm)
C_o	initial concentration of heavy metal (ppm)
D	diffusion coefficient (cm^2/s)
d_b	Bubble diameter (cm)
g	acceleration gravity time (cm/s^2)
k	first order reaction rate (cm/s)
K	volumetric mass transfer coefficient mass transfer factor (cm^3/s)
t	time (s)
T	temperature (°C)
V_g	superficial air velocity (cm/s)
V_s	volume of solution (L)

Greek symbols

α	constant (–)
ρ	solution Density (g/cm^3)
μ	solution viscosity (g/cm/s)

Dimensionless group

Fr	Froude number (–)
J_D	mass transfer factor (–)
Re	Reynolds number (–)
Sc	Schmidt number (–)

bed reactor containing ion exchange resin to remove Ni^{2+} and Pb^{2+} from synthetic wastewater. Industrial wastewaters containing Ni^{2+} and Pb^{2+} are produced by metal plating facilities, mining operations, metallurgical engineering, battery manufacturing processes, the production of paints and pigments, nuclear power plants, ceramic and glass industries. These heavy metals are not biodegradable and their presence in streams and lakes leads to bioaccumulation in living organisms, thereby causing health problems in animals, plants, and human beings [13]. The following parameters have been investigated to examine the performance of the reactor: Type of heavy metal ion (Ni^{2+} and Pb^{2+}), initial concentration of Ni^{2+} and Pb^{2+}, and air superficial velocity. In addition the present mass transfer data were correlated in terms of dimensionless correlation, which may be useful in the design and operation of such ion exchange conductors.

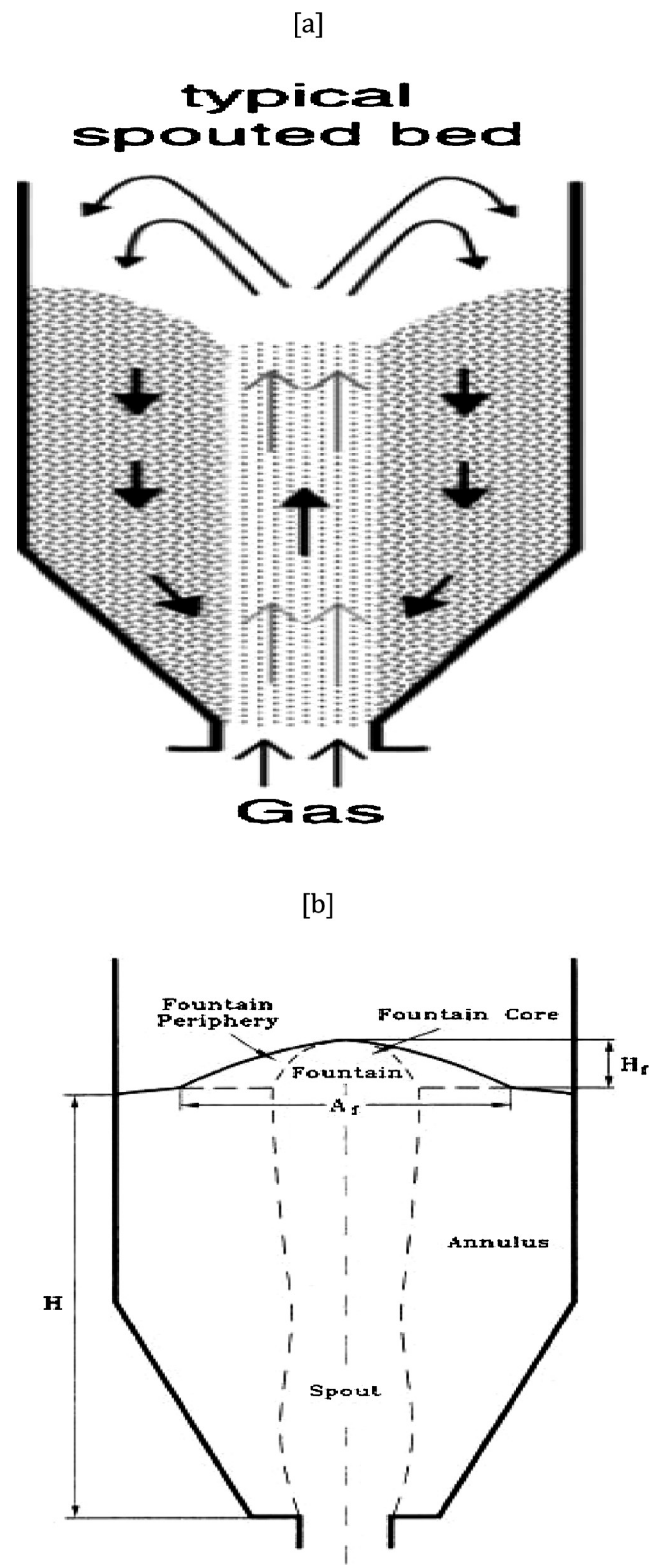

Fig. 1. (a) Particle motion in spouted bed, (b) different regimes of spouting bed.

2. Materials and methods

2.1. Materials

Fresh strong cation exchange resins, macro-porous AMBERJET 1200 Na, a product of ROHM&HAAS were used for each run. Table 1 shows the specifications of the used ion exchange resin. Nickel sulfate, lead nitrate and hydrochloric acid, were all AR-grade chemicals. Fig. 2 shows a schematic diagram of the experimental set-up. The spouted bed vessel consisted of a plexi-glass cylindrical column of 16 cm in diameter and 26 cm height. The cylindrical column was supported by a truncated cone of 10 cm height and an inclined angle of 37°46″. The truncated cone was provided with an inlet section of 2.5 cm diameter. Ion exchange resins were supported in the vessel by a sintered glass (G2) gas distributor placed at the end of inlet section. Air at different flow rates was introduced from the inlet section through the sintered glass to the spouted bed vessel thought a nozzle of 1 cm diameter. The flow rate of inlet air was regulated by a ball valve and measured by a calibrated rotameter. A non-return valve was fixed in the inlet