GAS ABSORPTION WITH CHEMICAL REACTION AND DESORPTION IN A FOAM-BED REACTOR

by

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Dedicated to

My Parents

CERTIFICATE

This is to certify that the thesis entitled "**Gas absorption with chemical reaction and desorption in a foam-bed reactor**", presented by **Mr. Amit A. Gaikwad**, is worthy of consideration for the award of the Doctor of Philosophy and is a record of the original and bona fide research work carried out by him under my guidance and supervision and that the results contained in it have not been submitted in part or in full to any other University or Institute for award of any degree or diploma.

January 28, 2008

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Art and science present two faces of human culture that reflect each other in many ways. Those of us seeking a topic which links, rather than simply reflects, both faces naturally, find much of their desire satisfied in the dazzling beauty and elegance of soap bubbles and foams; a subject which has attracted scientists, artists and children alike over hundreds of years. I wish to express from the core of my heart the gratitude and indebtedness to, and would like to thank, my research supervisor, Dr. Ashok N. Bhaskarwar, Professor of Chemical Engineering, Indian Institute of Technology, Delhi, for not only suggesting me the research problem on foam-bed reactors and guiding me throughout this research program but also for the encouragement, inspiration, motivation, and for sincere, untiring and timely advice which always helped in instilling within me a sense of optimism and confidence. He will always be in my heart for inculcating within me the qualities of perseverance and a sense of commitment towards one's work.

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Abstract

The present thesis concerns itself with the experimental analysis of simultaneous gas absorption, chemical reaction, and desorption in a semi-batch and a counter-current foam-bed reactor and theoretical verification of these experimental data. The system chosen is the carbonation of aqueous barium-sulfide solution. It involves the simultaneous absorption of carbon-dioxide gas into the aqueous barium-sulfide solution, fast chemical reaction between dissolved gas-phase species and the reactive species in the liquid phase, leading to the formation of a solid precipitate of barium carbonate and desorption of hydrogen-sulfide gas produced by the chemical reaction.

The experiments have been performed using both lean and pure carbon-dioxide gas. In a semi-batch foam-bed reactor, the effect of various parameters like height of the foam bed, initial concentration of aqueous barium-sulfide solution, flow rate of the gas, initial concentration of the carbon-dioxide gas in the gas mixture, volume of the liquid-phase reactant solution charged into the reactor, initial concentration of the surfactant added to the liquid phase, and the nature of the surfactant on the reactor performance have been studied. The conversion of barium sulfide increases with the increase in its initial concentration in the aqueous solution, flow rate of the gas, and initial concentration of the carbon-dioxide gas in the gas mixture. It decreases with the increase in the volume of the liquid-phase reactant solution charged into the reactor. Anionic surfactants do not foam aqueous barium-sulfide solutions, otherwise, the nature of surfactant (whether non-ionic or cationic) does not significantly affect the performance of the foam-bed reactor. The effects of foam height and of surfactant concentration on conversion reveal the

importance of the reverse diffusional flux of desorbing hydrogen-sulfide gas in determining the optimal performance of the reactor.

Three parameters, i.e. the foam height, liquid-flow rate into the foam section, and the number of inlets used to charge the liquid-phase reactant into the foam section have been experimentally explored in a counter-current foam-bed reactor. The experimental results indicate that the conversion of aqueous barium-sulfide solution increases with the increase in foam height and number of inlets used. An optimum liquid-flow rate corresponding to maximum conversion is obtained. Using the counter-current mode of operation, it is possible to suppress the desorption of hydrogen-sulfide gas to some extent.

Apart from the carbonation of barium sulfide, carbonation of sodium hydroxide (example of gas absorption with chemical reaction) using lean carbon-dioxide gas has also been studied in a counter-current foam-bed reactor. Comparison of these experimental data with the predictions of single-stage model of Bhaskarwar and Kumar (1984) shows that a counter-current foam-bed reactor performs better than a semi-batch foam-bed reactor.

Apart from these experiments, various other properties/ parameters like liquid hold-up, foam-bubble size, particle size of barium carbonate, and exit gas-phase concentration have also been measured experimentally for the carbonation of barium sulfide in a semi-batch foam-bed reactor. The resistance offered by surfactants like Triton X-100, CTAB, and Tween 80 for the absorption of carbon-dioxide gas into barium-sulfide solution has also been measured for various concentrations of the surfactants. Some experiments have been carried out in the bubble-column reactor to compare the performance of these reactors. Upto 15% higher conversions are obtained in a foam-bed reactor.

The models of Bhaskarwar and Kumar (1984) and Acharya (1994), which are applicable to the gas absorption with chemical reaction for lean gas and pure gas respectively, fail here and predict higher conversions of barium-sulfide solutions than those obtained experimentally in a semi-batch foam-bed reactor. This failure is attributed to the reverse diffusional flux of hydrogen-sulfide gas produced during the present gas-liquid reaction.

Sighting here the problem worth solving, three different models of a semi-batch foam-bed reactor have been developed for the absorption of lean gas with chemical reaction and desorption. The first model, i.e. the modified single-stage model is based on the single-stage model developed by Bhaskarwar and Kumar (1984). It neglects the gas-phase resistance everywhere and absorption and reaction occurring in the storage section. The second model, namely, the resistances-in-series model is a semi-empirical model used to calculate the overall mass-transfer coefficients using the experimental data.

A general model is finally developed to rigorously predict the performance of a foam-bed reactor under a wide range of conditions, and to remove the limitations of the modified single-stage model. The general model considers all coupled processes occurring in the reactor. This model also incorporates gas-phase and surface resistances, which were excluded in most of the previous models of the foam-bed reactor available in the literature. It involves two sub-models. The first sub-model is concerned with the foam section. The simultaneous gas absorption, reaction, and desorption in a single foam film surrounded by limited gas pockets have been simulated. Likewise, the storage-section analysis has also been performed by simulating the absorption-reaction-desorption process in surface liquid elements within the framework of the penetration theory and constitutes the second sub-model. The performance of the entire reactor under a variety of operating conditions has been simulated, using the two sub-models in a set of general material-balance equations (coupled nonlinear integro-differential equations) written over the storage section, obtaining the transient concentrations of liquid-phase species B, and gas-phase species A and P. The results of simulation have been validated with the experimental data. The general model has been able to successfully predict even the most unusual experimental results ascribable to desorption such as existence of an optimal foam height for a semi-batch operation of the reactor, besides the common ones for absorption.

A simple model has been developed for pure-gas absorption with chemical reaction and desorption in a foam-bed reactor. While modeling pure gas for this situation involving in a foam-bed reactor, two important differences in contrast to lean-gas systems have been considered, viz., there is no gas-phase resistance here, and there is a likely bubble shrinkage due to loss of the gaseous reactant from within the bubble as the foam matrix travels upward in the foam section.

Based on the experimental findings of the present investigation on carbonation of barium sulfide, a modified process-flow diagram has been proposed for the manufacture of barium carbonate from aqueous barium-sulfide solution and carbon-dioxide gas. Various foam-bed reactor configurations have also been proposed to maximise the absorption of carbon-dioxide gas and the desorption of hydrogen-sulfide gas independently. Based on the modified single-stage model, a graphical design procedure has been developed for the carbonation of barium sulfide in *n* foam-bed reactors connected in series and operated in a continuous mode.

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