

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

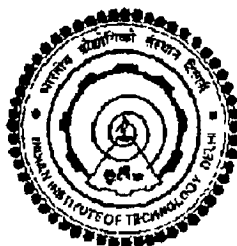
by

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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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*Amit A. Gaikwad*

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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.

# CONTENTS

SECTION	PAGE NO.
ABSTRACT	i
LIST OF FIGURES	xiii
LIST OF TABLES	xxvi
NOTATION	xxviii
CHAPTER 1. INTRODUCTION	1
Foams and foam-bed reactor	1
Objectives	7
CHAPTER 2. LITERATURE SURVEY	11
2.1 General	11
2.2 Gas absorption with chemical reaction in a foam-bed reactor	16
2.2.1 <i>Gas-liquid reactions</i>	16
2.2.2 <i>Gas-liquid reactions in the presence of solids</i>	23
2.3 Desorption with or without absorption in the presence of foam	26
2.4 Mathematical models of a foam-bed reactor	30
2.4.1 <i>Absorption of lean gas with chemical reaction</i>	30
2.4.2 <i>Absorption of a pure gas with chemical reaction</i>	45
2.4.3 <i>Absorption of lean gas with chemical reaction and desorption</i>	49
CHAPTER 3. THEORY	51
3.1 Introduction	51
3.2 Physical and chemical phenomena occurring in a foam-bed reactor	54

<b>3.3 Lean-gas models for gas absorption with chemical reaction and desorption</b>	55
<b>3.3.1 Modified single-stage model</b>	55
<b>3.3.2 Resistances-in-series model</b>	59
<b>3.3.2.1 Unsteady-state model</b>	61
<b>3.3.3 General model</b>	63
<b>3.3.3.1 Assumptions</b>	63
<b>3.3.3.2 Model development</b>	64
<b>3.3.3.3 Method of solution</b>	77
<b>3.4 Model for pure-gas absorption with chemical reaction and desorption</b>	79
<b>3.5 Design of a foam-bed reactor system</b>	83
<b>CHAPTER 4. EXPERIMENTAL WORK</b>	84
<b>4.1 Introduction to the process in practice</b>	84
<b>4.2 Mechanism and kinetics of carbonation of barium sulfide</b>	89
<b>4.3 Carbonation of barium sulfide in a semi-batch foam-bed reactor</b>	91
<b>4.3.1 Experimental set-up</b>	91
<b>4.3.1.1 Lean-gas absorption</b>	91
<b>4.3.1.2 Pure-gas absorption</b>	94
<b>4.3.2 Details of the reactor column</b>	95
<b>4.3.3 Materials used</b>	97
<b>4.3.4 Preparation of reactant solution</b>	98
<b>4.3.5 Experimental procedure</b>	100

4.3.6	<i>Method of analysis of the samples</i>	101
4.3.7	<i>Parameters and their ranges studied</i>	102
4.3.8	<i>Measurement of properties/ parameters</i>	105
4.3.8.1	<i>Liquid hold-up</i>	105
4.3.8.2	<i>Bubble size</i>	105
4.3.8.3	<i>Particle size</i>	106
4.3.8.4	<i>Interfacial resistance</i>	107
4.3.8.5	<i>Exit gas-phase concentration</i>	112
4.3.8.6	<i>Surface tension</i>	113
4.4	<b>Counter-current foam-bed reactor</b>	114
4.4.1	<i>Introduction</i>	114
4.4.2	<i>Carbonation of sodium hydroxide using lean carbon-dioxide gas</i>	116
4.4.3	<i>Carbonation of barium sulfide using lean and pure carbon-dioxide gas</i>	117
	<b>CHAPTER 5. RESULTS AND DISCUSSION</b>	<b>119</b>
5.1	<b>Variation of various properties/ parameters</b>	119
5.1.1	<i>Liquid hold-up profiles</i>	119
5.1.2	<i>Bubble-size analysis</i>	122
5.1.3	<i>Particle-size distribution</i>	130
5.1.4	<i>Surfactant-film mass-transfer coefficients</i>	136
5.1.5	<i>Surface tension</i>	138
5.2	<b>Mass-transfer coefficient estimation for absorption of a lean gas</b>	

<b>with desorption in a semi-batch foam-bed reactor using resistances-</b>	
<b>in-series model</b>	139
<i>5.2.1 Calculation of overall mass-transfer coefficient</i>	140
<i>5.2.2 Development of an empirical correlation</i>	150
<i>5.2.3 Calculation of gas-phase mass-transfer coefficient</i>	151
<b>5.3 Effect of various parameters on the performance of a semi-batch</b>	
<b>foam-bed reactor for absorption of a lean gas with desorption</b>	154
<i>5.3.1 Comparison of present experimental and reported data on</i>	
<i>carbonation of barium sulfide with single-stage model</i>	154
<i>5.3.2 Comparison of present experimental data on carbonation of</i>	
<i>barium sulfide with modified single-stage model and general</i>	
<i>model</i>	156
<i>5.3.2.1 Effect of height of foam bed</i>	156
<i>5.3.2.1.1 Effect of liquid hold-up</i>	163
<i>5.3.2.2 Effect of initial concentration of aqueous barium-sulfide</i>	
<i>solution</i>	164
<i>5.3.2.3 Effect of gas-flow rate</i>	170
<i>5.3.2.4 Effect of initial concentration of carbon dioxide in the</i>	
<i>gas mixture</i>	176
<i>5.3.2.5 Effect of volume of aqueous barium-sulfide solution</i>	
<i>charged into the reactor</i>	181
<i>5.3.2.6 Effect of concentration of surfactant</i>	186
<i>5.3.2.7 Effect of nature of surfactant</i>	193

5.3.3	<i>Comparison of data from literature on carbonation of barium sulfide with resistances-in-series model and unsteady state model</i>	196
5.3.4	<i>Comparison with a bubble-column reactor</i>	199
5.4	<b>Pure-gas absorption and desorption in a semi-batch foam-bed reactor</b>	203
5.4.1	<i>Comparison of the model of Acharya (1994) with the experimental data on carbonation of barium sulfide</i>	203
5.4.2	<i>Comparison of the model of Acharya (1994) modified for desorption with the experimental data on carbonation of barium sulfide</i>	204
5.4.3	<i>Comparison with a bubble-column reactor</i>	212
5.5	<b>Counter-current foam-bed reactor</b>	213
5.5.1	<i>Comparison of the single-stage model with the experimental data on the carbonation of sodium hydroxide using lean carbon-dioxide gas in a counter-current foam-bed reactor</i>	213
5.5.2	<i>Carbonation of barium sulfide using lean and pure carbon-dioxide gas</i>	217
5.5.2.1	<i>Effect of foam height</i>	217
5.5.2.2	<i>Effect of liquid-flow rate into the foam section</i>	220
5.5.2.3	<i>Effect of number of inlets used for charging the liquid into the foam section</i>	220
5.6	<b>Design chart for a foam-bed reactor system</b>	223

<b>CHAPTER 6. CONCLUSIONS</b>	<b>229</b>
<b>REFERENCES</b>	<b>235</b>
<b>APPENDICES</b>	<b>243</b>
<b>APPENDIX A</b>	
<b>Method of solution for the general model</b>	<b>243</b>
<i>A.1 Sub-model for surface liquid elements in the storage section</i>	243
<i>A.2 Sub-model for the foam section</i>	247
<i>A.3 Numerical solution of the material-balance equations in         storage section</i>	252
<b>APPENDIX B</b>	
<b>Sample calculation for the model of Sonc and Grlic (2004)</b>	<b>254</b>
<i>B.1 Determination of surfactant concentration in aqueous solutions</i>	254
<i>B.1.1 Non-ionic surfactants</i>	254
<i>B.1.2 Cationic surfactants</i>	254
<i>B.2 Calculation of distribution coefficients</i>	255
<b>APPENDIX C</b>	
<b>Calibration of rotameters</b>	<b>259</b>
<b>APPENDIX D</b>	
<b>Preparation and standardization of solutions</b>	<b>260</b>
<i>D.1 Preparation of reagents</i>	260
<i>D.2 Standardization</i>	261
<b>APPENDIX E</b>	
<b>Determination of NaOH and Ba<sup>++</sup> ion concentrations</b>	<b>263</b>

<i>E.1 Determination of NaOH concentration</i>	263
<i>E.2 Determination of Ba<sup>++</sup> ion concentration</i>	263
<b>APPENDIX F</b>	
<b>Measurement of viscosity</b>	264
<b>APPENDIX G</b>	
<b>Removal of surfactant from barium carbonate</b>	266
<b>APPENDIX H</b>	
<b>Calculation of K<sub>s</sub> values from Blank and Roughton (1960)</b>	267
<b>APPENDIX I</b>	
<b>Sample calculation for resistances-in-series model</b>	271
<i>I.1 Determination of parameters</i>	271
<i>I.2 Sample calculation</i>	271
<b>PUBLICATIONS</b>	274
<b>BIODATA</b>	277