

ADSORPTION KINETICS OF AN ION-EXCHANGE COLUMN



Ms. Anchale Tresattayawed

A Thesis Submitted in Partial Fulfilment of the Requirements
for the Degree of Master of Science
The Petroleum and Petrochemical College, Chulalongkorn University
in Academic Partnership with
The University of Michigan, The University of Oklahoma,
and Case Western Reserve University

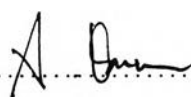
2000

ISBN 974-334-116-1


119296745

Thesis Title : Adsorption Kinetics of an Ion-Exchange Column
By : Ms. Anchale Tresattayawed
Program : Petrochemical Technology
Thesis Advisors : Prof. James O. Wilkes
Dr. Pramoch Rangsunvigit

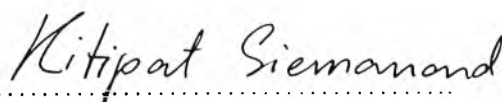
Accepted by the Petroleum and Petrochemical College, Chulalongkorn University, in partial fulfillment of the requirements for the Degree of Master of Science.


..... College Director
(Prof. Somchai Osuwan)

Thesis Committee:


.....
(Prof. James O. Wilkes)


.....
(Dr. Pramoch Rangsunvigit)


.....
(Dr. Kitipat Siemanond)

บทคัดย่อ

นางสาวอัญจารี ตริสตัทยาเวทย์: กลไกการดูดซับของการแลกเปลี่ยนไอออนในคอลัมน์ (Adsorption Kinetics of an Ion Exchange Column) อ. ที่ปรึกษา : ศ. เจมส์ โอ วิลค์ และ ดร. ปราโมช รังสรรค์วิจิตร : 62 หน้า ISBN 974-334-116-1

การวิจัยนี้ศึกษากลไกการดูดซับของแคลเซียมไอออนและแมกนีเซียมไอออนจากสารละลายไอออนเชิงเดี่ยวและไอออนเชิงผสมต่อไฮโดรเจนไอออนบนเรซินที่มีประจุบวก(Dowex50-8x) การศึกษาได้ทำในคอลัมน์แบบฟลูอิดไดซ์เบดที่อุณหภูมิห้อง ความสามารถในการดูดซับของเรซินหาจากการทดลองแบบกะ(batch) ผลการทดลองพบว่าความสามารถในการดูดซับของเรซินประมาณ 1.13 มิลลิกรัมวาลেন্টต่อมิลลิลิตร นอกจากนี้ได้ตรวจสอบลักษณะการไหลของของเหลวในคอลัมน์โดยการทดลองแบบไม่มีการดูดซับในคอลัมน์ ผลการทดลองพบว่าลักษณะการไหลของของเหลวในคอลัมน์เป็นแบบฟลูอิดไดซ์เบดที่สมบูรณ์ จากผลการทดลองของการดูดซับของไอออนเชิงเดี่ยวพบว่าอัตราการแลกเปลี่ยนระหว่างแคลเซียมไอออนและไฮโดรเจนไอออนบนเรซินสูงกว่าอัตราการแลกเปลี่ยนระหว่างแมกนีเซียมไอออนและไฮโดรเจนไอออน สำหรับระบบของไอออนเชิงผสมซึ่งมีอัตราส่วนของความเข้มข้นเริ่มต้นเท่ากับ 1:1 อัตราการแลกเปลี่ยนระหว่างแคลเซียมไอออนและไฮโดรเจนไอออนบนเรซินก็ยิ่งสูงกว่าอัตราการแลกเปลี่ยนระหว่างแมกนีเซียมไอออนและไฮโดรเจนไอออน ลักษณะการดูดซับที่ซับซ้อนของระบบปฏิบัติการแบบฟลูอิดไดซ์เบดในคอลัมน์สามารถอธิบายได้โดยแบบจำลอง แบบจำลองถูกพัฒนาขึ้น โดยมีสมมติฐานที่ว่าระบบปฏิบัติการสามารถอธิบายได้จาก CSTR PFR และ ระยะเวลาของการตอบสนองของ pH อิเล็กโทรด

ABSTRACT

4171003063: PETROCHEMICAL TECHNOLOGY PROGRAM

KEYWORD: Ion exchange/Cation exchanger/Fluidized-bed/Kinetics

Ms. Anchale Tresattayawed: Adsorption Kinetics of an
Ion-Exchange Column.

Thesis Advisors: Prof. James O. Wilkes and Dr. Pramoch
Rangsunvigit, 62 pp, ISBN 974-334-116-1.

The adsorption kinetics of Ca^{2+} and Mg^{2+} from single-ion and mixed-ion solutions on a strong-acid cation resin (Dowex50-X8) was investigated. The process was carried out in the fluidized-bed column at room temperature. In the beginning, total adsorption capacities were determined using batch experiments. The results showed that this resin had the total adsorption capacity about 1.13 meq/ml. A no adsorption test was also carried out to examine the characteristics of the flow in the column. It was found that this system exhibits a good fluidized-bed pattern. The results of the single ion adsorption tests indicated that the exchange rate of Ca^{2+} for H^+ on the resin was higher than that of Mg^{2+} . For the mixed-ion system with a Ca^{2+} and Mg^{2+} initial concentration ratio of 1: 1, the exchange rate of Ca^{2+} for H^+ on the resin was also higher than that of Mg^{2+} . The complicated adsorption behavior of the fluidized-bed operation can be explained using a simple model. The model was developed based on the assumption that the operation can be represented with a mixed flow reactor, a plug flow reactor and the response time of the pH electrode.

ACKNOWLEDGEMENTS

I would like to gratefully give special thanks to my advisor, Professor James O. Wilkes for his constructive criticism and valuable suggestions. I am also deeply indebted to my co-advisors, Dr. Pramoch Rangsunvigit for his intensive suggestions, valuable guidance and vital help throughout this research work.

I greatly appreciate all the professors who have tendered invaluable knowledge to me at the Petroleum and Petrochemical College, Chulalongkorn University.

I wish to express my thanks to all of my friends and to the college staff who willingly gave me warm support and encouragement and to the Petroleum Authority of Thailand for financial support during the period of the study.

Finally, I am deeply indebted to my family for my love, understanding, encouragement, and for being a constant source of inspiration.

TABLE OF CONTENTS

	PAGE
Title Page	i
Abstract (in English)	iii
Abstract (in Thai)	iv
Acknowledgements	v
Table of Contents	vi
List of Tables	ix
List of Figures	x
CHAPTER	
I INTRODUCTION	1
II BACKGROUND AND LITERATURE SURVEY	3
2.1 Ion-Exchange Equilibrium and Kinetics	3
2.1.1 Ion-Exchange Equilibrium	3
2.1.2 Ion-Exchange Kinetics	4
2.2 Modes of Operation	6
2.2.1 Batch Operation	6
2.2.2 Fixed-Bed Operation	6
2.2.3 Fluidized-Bed Operation	7
2.3 Model Development	9
2.3.1 A Model for the Response Time of a pH Electrode	9
2.3.2 A Model for the Batch Operation with an Adsorption	10

CHAPTER	PAGE
2.3.3 A Model for a Fluidized-Bed Operation without an Adsorption	13
2.3.4 A Model for a Fluidized-Bed Operation with an Adsorption	14
2.3.5 Mathematical Procedure	16
III EXPERIMENTAL SECTION	19
3.1 Equipment Setup	19
3.2 Experimental Procedure	20
3.2.1 Resin Preparation	20
3.2.2 Ion Exchange Experiment	20
3.2.2.1 pH Calibration	20
3.2.2.2 Batch Experiment	21
3.2.2.3 Continuous Flow Experiment	22
IV RESULTS AND DISCUSSION	23
4.1 Response Time Experiment	23
4.2 Batch Operation	24
4.3 No Adsorption in Fluidized-Bed Ion-Exchange Column	26
4.4 Adsorption in Fluidized-Bed Exchange Column	27
V CONCLUSIONS AND RECOMMENDATION	41
5.1 Conclusions	41
5.2 Recommendation	42
REFERENCES	43

CHAPTER	PAGE
APPENDICES	44
CURRICULUM VITAE	62

LIST OF TABLES

TABLE	PAGE
4.1 The effect of flow rate on the response time constant	24
4.2 Model parameters in the batch operation with different solutions	25
4.3 The experimental conditions with adsorption in the fluidized -bed column	27
4.4 Summary of the rate and equilibrium constants in the fluidized -bed operation	28
A Bock setting of Labtech Notebook	44
B.1 The analysis of response time experiment in batch operation	45
B.2 The analysis of response time experiment in fluidized-bed column with $v = 1.67$ ml/s	46
B.3 The analysis of response time experiment in fluidized-bed column with $v = 2.17$ ml/s	47
B.3 The analysis of response time experiment in fluidized-bed column with $v = 2.50$ ml/s	48
C.1 Modeling of the batch adsorption rates for Ca^{2+}	49
C.2 Modeling of the batch adsorption rates for Mg^{2+}	50
C.3 Modeling of the batch adsorption rates for Na^+	51
C.4 Modeling of the batch adsorption rates for mixed-ion of Ca^{2+} and Mg^{2+}	52
D Modeling of the no adsorption operation	53
E.1 Modeling of the continuous adsorption rates for Ca^{2+}	54
E.2 Modeling of the continuous adsorption rates for Mg^{2+}	56
E.3 Modeling of the continuous adsorption rates for Na^+	58
E.4 Modeling of the continuous adsorption rates for the mixed-ion of Ca^{2+} and Mg^{2+}	60

LIST OF FIGURES

FIGURE	PAGE
2.1 Representation of the response time experiment	9
2.2 Notation for the diffusion in the resin particle	10
2.3 Representation of ion-exchange column without adsorption	13
2.4 Representation of ion-exchange column with adsorption	14
2.5 A diagram of the numerical method	18
3.1 Schematic of the continuous operation	20
3.2 Experimental setup for batch operation	21
4.1 The comparison of the experimental and modeled response times by measuring the hydrogen concentration in a batch system with mixing rate of 750 rpm	30
4.2 The comparison of the experimental and modeled response times by measuring the hydrogen concentration in the fluidized-bed operation with flow rate 1.67 ml/s	30
4.3 The comparison of the experimental and modeled response times by measuring the hydrogen concentration in the fluidized-bed operation with flow rate 2.17 ml/s	31
4.4 The comparison of the experimental and modeled response times by measuring the hydrogen concentration in the fluidized-bed operation with flow rate 2.5 ml/s	31
4.5 The concentration of desorbed hydrogen ions for different cationic salts with the total initial concentration 0.2 N	32
4.6 The concentration of desorped hydrogen ions for mixed-ion solution of Ca^{2+} and Mg^{2+} with total initial concentration 0.2 N	32

FIGURE	PAGE
4.7 The cation adsorbed on the resin(q) as a function of time for various cationic salts	33
4.8 The comparison of the experimental and theoretical batch adsorption rates for Ca^{2+}	33
4.9 The comparison of the experimental and theoretical batch adsorption rates for Mg^{2+}	34
4.10 The comparison of the experimental and theoretical batch adsorption rates for Na^+	34
4.11 The comparison of the experimental and theoretical batch adsorption rates for mixed-ion of Ca^{2+} and Mg^{2+}	35
4.12 The comparison of the experimental and theoretical batch adsorption rates for Ca^{2+} in mixed-ion solution	35
4.13 The comparison of the experimental and theoretical batch adsorption rates for Mg^{2+} in mixed-ion solution	36
4.14 The comparison of no adsorption experiment and model with one CSTR and one PFR in series	36
4.15 The comparison of no adsorption experiment and model with two CSTRs and one PFR in series	37
4.16 The comparison of no adsorption experiment and model with three CSTRs and one PFR in series	37
4.17 The comparison of the experimental and theoretical values of the hydrogen concentration leaving the PFR in an adsorption operation with CaCl_2	38
4.18 The comparison of the experimental and theoretical values of the hydrogen concentration leaving the PFR in an adsorption operation with MgCl_2	38

FIGURE	PAGE
4.19 The comparison of the experimental and theoretical values of the hydrogen concentration leaving the PFR in an adsorption operation with NaCl	39
4.20 The comparison of the experimental and theoretical values of the hydrogen concentration leaving the PFR in an adsorption operation with mixed-ion solution of Ca^{2+} and Mg^{2+}	39
4.21 The comparison of the experimental and theoretical values of the hydrogen concentration leaving the PFR in an adsorption operation with Ca^{2+} in mixed-ion solution	40
4.22 The comparison of the experimental and theoretical values of the hydrogen concentration leaving the PFR in an adsorption operation with Mg^{2+} in mixed-ion solution	40