

بسم الله الرحمن الرحيم



SALWA AKL



شبكة المعلومات الجامعية

التوثيق الالكتروني والميكروفيلم



SALWA AKL

جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
علي هذه الأقراص المدمجة قد أعدت دون أية تغيرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



SALWA AKL



بعض الوثائق الأصلية تالفة



SALWA AKL



بالرسالة صفحات

لم ترد بالأصل



SALWA AKL

B 17454

4

**ALEXANDRIA UNIVERSITY
FACULTY OF ENGINEERING**

**EVALUATION OF ENERGY RECOVERY AS A
FUNCTION OF FEED SALINITY IN REVERSE
OSMOSIS UNITS**

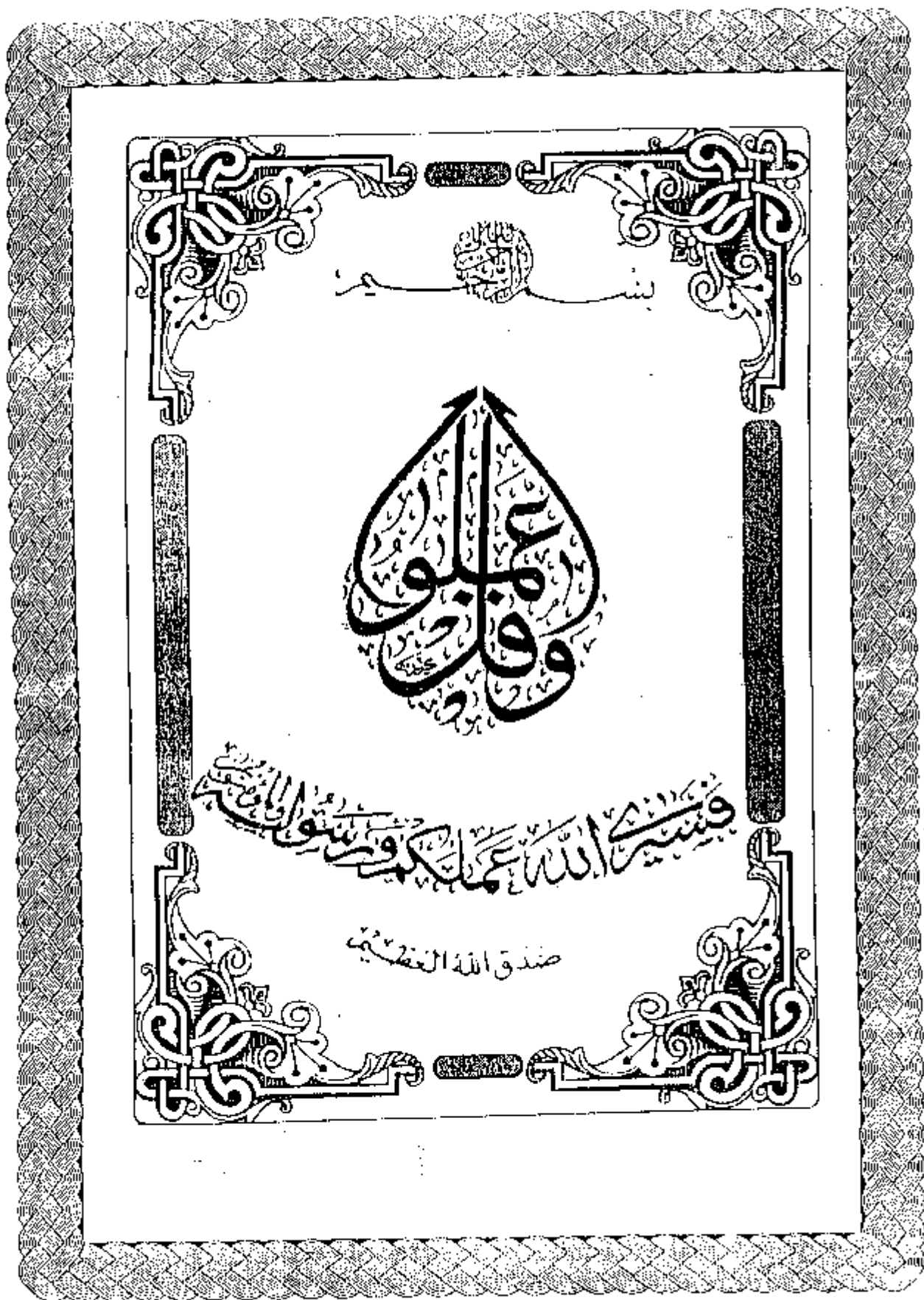
A Thesis Submitted To The Department Of
Chemical Engineering In Partial Fulfillment Of
The Requirements For The Degree Of M.Sc. In Chemical
Engineering

**BY
ENG. MAHA MOHAMED KAMAL ELDIN ATTIA**

**SUPERVISED BY
PROF. DR. MOHAMED AMIN MANDIL
PROF. DR. HASSAN ABDEL MONIEM FARAG
PROF. DR. MONA MAHMOUD NAIM**

**CHEMICAL ENGINEERING DEPARTMENT
FACULTY OF ENGINEERING
ALEXANDRIA UNIVERSITY**

1995



بسم الله الرحمن الرحيم

وَاللَّهُ أَعْلَمُ

فَتَنبِيْهِكَ اللَّهُ بِمَا يَكُونُ فِي الْقُلُوبِ

صَدَقَ اللَّهُ الْعَظِيمُ

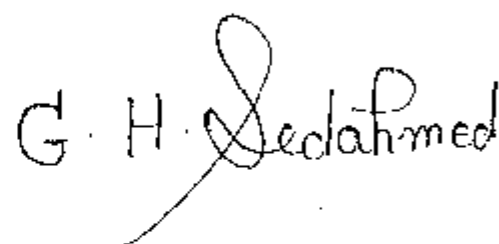
We certify that we read this thesis and that in our opinion it is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science.

Exam. Committee:

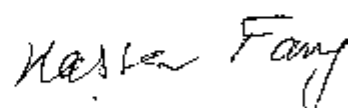
- 1- Prof. Dr. Mahmoud A. El-Refaei
Dept. of Chemical Engineering
Faculty of Engineering
Cairo University



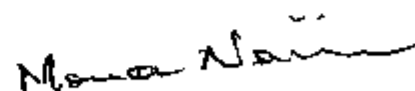
- 2- Prof. Dr. Gomaa H. S. Ahmed
Dept. of Chemical Engineering
Faculty of Engineering
Alexandria University



- 3- Prof. Dr. Hassan A. Farag
Dept. of Chemical Engineering
Faculty of Engineering
Alexandria University



- 4- Prof. Dr. Mona M. Naim
Dept. of Chemical Engineering
Faculty of Engineering
Alexandria University



I DEDICATE THIS WORK TO
MY PARENTS, MY HUSBAND
AND MY CHILDREN

ACKNOWLEDGMENT

I would like to express my most sincere appreciation and deepest gratitude to Prof. Dr. *M.A. Mandil* for initiating this work and for his great interest, guidance and constant supervision throughout the work.

I would also like to extend my deepest thanks to Prof. Dr. *H. A. Farag* and Prof. Dr. *M. M. Naim* for their keen interest, constant guidance, supervision and unfailing help, and for revising the manuscript.

My thanks are also due to Dr. *E. Abdel Ghafour* for his valuable ideas and suggestions resulting from his highly regarded expertise in the field of reverse osmosis.

Last, but not least, I wish to thank my husband Dr. *A. H. Tewfick* for availing his computer programming abilities, his patience and constant encouragement.

Table of Contents

	Page
SUMMARY	
Chapter I : INTRODUCTION	1
1.1 Water	1
1.1.1 Water Resources on Earth	1
1.1.2 Availability of Fresh Water	5
1.1.3 Need for Potable Water	8
1.1.4 Saline Water	12
1.1.5 Need for Desalination.	16
1.2 Desalination History	19
1.3 Desalination Technology	21
1.3.1 Distillation Processes	21
1.3.1.1 Multi-effect distillation	22
1.3.1.2 Multistage flash distillation	22
1.3.1.3 Vapor compression	23
1.3.2 Membrane Processes	24
1.3.2.1 Electrodialysis	24
1.3.2.2 Reverse Osmosis	26
1.3.3 Other Processes	27
1.3.3.1 Solar distillation	27
1.3.3.2 Ion exchange	28
1.3.3.3 Freezing	28
1.3.3.4 Membrane distillation	30
1.3.3.5 Pervaporation	31
1.4 Desalination World Market Structure.	33
1.5 Market Growth of Reverse Osmosis	35

1.6	Reverse Osmosis Process	37
1.6.1	Process Development	37
1.6.2	Membranes	39
1.6.3	Factors Affecting Performance	44
1.7	Osmotic Pressure	49
1.7.1	Methods Available for Calculation	49
1.7.2	Selected Method for Calculation of Osmotic Pressure	53
1.7.3	Calculation of Osmotic Pressure	54
1.7.4	Basic Feed Water Data	57
1.7.5	Simulated Sea Water Analysis	59
1.7.6	Comparison of Osmotic Pressure & Values Obtained by Different Methods	61
1.7.7	Sea Water Osmotic Pressures Calculated by Different Methods	63
1.8	Literature Survey	64
Chapter II: PERMEATORS AND THEIR DESIGN		69
2.1	Considerations Affecting Choice of Permeators	69
2.2	Types pf Permeators and their Specifications	72
2.3	Staging	76
2.3.1	Single Stage Selected for Study.	77
Chapter III: PERMEATOR PERFORMANCE		79
3.1	Factors Influencing Performance of Permeators	79
3.1.1	General Factors	79
3.1.2	Pressure Correction Factor	80
3.1.3	Membrane Flux Retention Coefficient	81
3.1.4	Temperature Correction Factor	82

3.2	Permeator Productivity	83
3.3	Restricting Considerations	84
3.4	Brine Osmotic Pressure as a Limiting Factor	85
3.5	Maximum and Minimum Allowable Brine Flow Rates	85
Chapter IV: SALT PASSAGE		88
4.1	Salt Passage Correction Factor	90
4.2	Calculation of Salt Passage Correction Factor	92
4.3	Salt Passage as a Limiting Factor in Permeator Operation	94
4.4	Chloride Concentration in Product	94
Chapter V: PRODUCTIVITY AS A FUNCTION OF RECOVERY		95
5.1	Computer Program Logic	95
5.2	Diagrammatic Representation of Results	100
5.3	Restricting Factors Defining Scopes of Design Limits	101
5.3.1	Maximum Flow Rate of Brine	101
5.3.2	Minimum Flow Rate of Brine	102
5.3.3	The Ratio of the Osmotic Pressure and the Operating Pressure of Brine	103
Chapter VI: MAXIMUM TECHNICALLY FEASIBLE RECOVERY		115
6.1	Concept	115
6.2	Definition	116
6.3	For Sea Water	116
6.4	For Brackish Water	120

Chapter VII: ENERGY REQUIREMENTS FOR REVERSE OSMOSIS	123
7.1 Calculation Procedures	123
7.2 Energy Requirement and Feed Water Salinity.	124
Chapter VIII: ENERGY RECOVERY	126
8.1 Energy Recovery as a Concept	126
8.2 Energy Recovery Devices	127
8.2.1 Reverse Running Multistage Centrifugal Pumps	128
8.2.2 Pelton Wheels	130
8.3 Recoverable Energy	132
8.4 Factors Affecting Energy Recovery	134
8.5 Energy Recovery Calculation Procedure	135
8.6 Feed Salinity and Energy Recovery	137
8.6.1 Operating Pressure	137
8.6.2 Brine Pressure	137
8.6.3 Brine Flow Rate	138
Chapter IX: WATER COST	139
9.1 Factors Affecting Water Cost	139
9.2 Cost Calculation Procedures	143
9.3 Computer Programs	144
9.3.1 Water Cost Without Energy Recovery	144
9.3.2 Water Cost With Energy Recovery	147
9.4 Cost Saving due to Energy Recovery	149
9.4.1 Effect of Salinity on Cost Saving.	149
Chapter X: CONCLUSIONS	157

REFERENCES	160
APPENDIX: Computer Programs	166