

Contents

1	Introduction.....	1
2	Objectives.....	4
3	State of the Art of Spiral Wound Technology.....	6
3.1	Introduction	6
3.2	Membrane	10
3.3	Feed Spacer.....	10
3.4	Permeate Spacer	12
3.5	Permeate Collecting Pipe.....	12
3.6	Module Housing	13
3.7	Membrane Cartridge	14
4	Open-Channel Spiral Wound Module.....	18
4.1	ST-Module® Structure	18
4.2	Basic Module Parameters	21
4.2.1	Active Membrane Area and Packing Density	21
4.2.2	Feed Spacer Porosity and Flow Velocity.....	22
4.2.3	Hydraulic Diameter.....	25
5	Experimental Equipment	27
5.1	RO Pilot Plant Set-up	27
5.1.1	Process Procedure.....	27
5.1.2	Process Equipment.....	29
5.1.3	Process Control.....	31
5.2	Flat Channel Set-up	35
6	ST-Module® Modelling.....	38
6.1	Pressure Loss	38
6.2	Mass Transfer through the Membrane	41
6.2.1	The Solution-Diffusion Model	42
6.2.2	The Kedem-Katchalsky Model	45
6.2.3	The Spiegler-Kedem Model	46
6.2.4	The Finely-Porous Model	47
6.3	The Film Model.....	49
6.4	Identification of a Sherwood Correlation.....	51
6.4.1	Combined Solution-Diffusion/Film Model	53
6.4.2	Combined Kedem-Katchalsky/Film Model	55
6.4.3	Combined Spiegler-Kedem/Film Model.....	56
6.4.4	Combined Finely-Porous/Film Model	56
6.5	Physicochemical Solution Properties	57
6.5.1	Density	57

6.5.2	Viscosity	58
6.5.3	Diffusion Coefficient	58
6.5.4	Osmotic Pressure.....	60
7	Experimental Investigations.....	61
7.1	Pressure Loss	61
7.1.1	Module Cartridge.....	61
7.1.2	Flat Channel.....	62
7.2	Water Permeability.....	63
7.3	Mass Transfer	63
8	Results and Discussion	67
8.1	Experimental Data Processing	67
8.1.1	Pressure Loss	67
8.1.2	Water Permeability.....	67
8.1.3	Mass Transfer	68
8.1.4	Parameter Approximation	72
8.2	Pressure Loss Results	73
8.3	Water Permeability Results	78
8.4	Mass Transfer Results	80
8.4.1	Sodium Chloride Solutions.....	80
8.4.2	Magnesium Sulphate Solutions.....	87
8.5	Sherwood Correlation.....	93
9	ST-Module® Simulation	98
9.1	Program Structure and Algorithm	98
9.2	Simulation Results.....	102
9.2.1	Simulation Tool Verification.....	103
9.2.2	Module Design Optimisation	104
9.2.3	Optimal Operating Conditions	113
10	Feed Channel Modelling and Simulation	116
10.1	Applied CFD Code	118
10.1.1	The Finite Volume Method (FVM)	118
10.1.2	Mesh Generation.....	122
10.1.3	Pre-Processing.....	123
10.1.4	Solving of the System of Equations.....	124
10.1.5	Post-Processing	124
10.2	Pressure Loss Simulations.....	124
10.2.1	Simulation Settings	124
10.2.2	Simulation Results	126
10.3	Process Simulations.....	128
10.3.1	Overall Simulation Settings	128

10.3.2	Simulation Results	129
10.3.3	Conclusions.....	139
11	Implication for Optimised ST-Module® Design	141
12	Conclusions and Outlook	144
13	Appendix.....	146
14	References	154