Contents

Contents IV

Kurzfassung VII

Abstract VIII

List of Tables IX

List of Figures XI

List of Symbols XV

List of Abbreviations XX

1. Introduction 1

2. Theoretical Background 5
2.1. Design and Use of Wiped Film Evaporators in Industrial Thermal Separation 5
2.1.1. Working Principle of Wiped Film Evaporators and Common Use Cases . . . 5
2.1.2. Factors Affecting Process Performance 6
2.2. Heat Transfer Characteristics and Flow Behavior in Wiped Film Evaporators 10
2.2.1. Flow Regimes and Their Effect on Fluid Dynamics 10
2.2.2. Heat and Mass Transfer in Mechanically Agitated Film Flows 13
2.2.3. Stability of Thin Liquid Films and Dynamics of Film Rupture 17
2.3. Challenges and Uncertainties of Wiped Film Evaporators during Design and Operation 19
2.4. Scope and Objectives of the Present Work 19

3. Methodological Approach 21
3.1. Experimental Setup and Operation of the Miniplant with a Wiped Film Evaporator . 21
3.1.1. Residence Time Measurements 25
3.1.2. Image-Based Analysis of Liquid Film Behavior 26
3.1.3. Calculation of Experimental Heat Transfer Coefficients 27
3.2. Experimental System Characterization and Evaluation of Uncertainties 29
3.2.1. Mass and Energy Balance Characterization 29
3.2.2. Determination of Experimental Uncertainties 29

4. Characterization of the Used Model Fluids 31
4.1. Introduction 32
4.2. Experimental Methods 33
4.2.1. Investigated Fluids 33
4.2.2. Refractive Index Measurements 34
4.2.3. Density Measurements 34
4.2.4. Viscosity Measurements 35

4.2.5. Measurements of Surface Tension . . . 35
4.2.6. Evaluation of the Measurements . . . 35
4.3. Results and Discussion . . . 37
4.3.1. Experimental Results of the Pure Components . . . 37
4.3.2. Experimental Data of Binary Mixtures . . . 45
4.3.3. Estimation of Excess Properties . . . 56
4.4. Conclusions . . . 62

5. Experimental Results of Fluid Dynamics during Evaporation 65
5.1. Evaporation Effects on Residence Time in Wiped Film Evaporators with Roller Wipers 65
5.1.1. Introduction . . . 65
5.1.2. Experimental Setup . . . 67
5.1.3. Results and Discussion . . . 71
5.1.4. Conclusion . . . 79
5.2. Product-side Heat Transfer Measurements under Evaporation Conditions . . . 83
5.3. Detailed Analysis of the Film along the Height during Evaporation . . . 85

6. Modeling of Fluid Dynamics in Wiped Film Evaporators 87
6.1. Structure of the Developed Model . . . 87
6.1.1. Force and Momentum Balance . . . 88
6.2. Modeling and Simulation of the Fluid Dynamics without Evaporation . . . 90
6.2.1. Introduction . . . 93
6.2.2. Modeling . . . 93
6.2.3. Results and Discussion . . . 102
6.2.4. Conclusions and Outlook . . . 106
6.3. Corrigendum . . . 108
6.3.1. Corrigendum to “A new approach to simulate the fluid dynamics in a wiped film evaporator using Modelica” [Chem. Eng. Res. Des. 161 (2020) 115–124] 108
6.4. Findings of Fluid Dynamic Simulation and Limits of Modeling without Heat Transfer 110

7. Modeling of Fluid Dynamics and Heat Transfer in Wiped Film Evaporators during Evaporation 111
7.1. Modeling of Fluid Dynamics in Wiped Film Evaporators during Evaporation . . . 112
7.1.1. Introduction . . . 113
7.1.2. Model Equations and Structure . . . 114
7.1.3. Results and Discussion . . . 121
7.1.4. Conclusion . . . 127
7.1.5. Acknowledgements . . . 128
7.2. Assessment of the Model and Comparison to Experimental Results . . . 131
7.3. Recommendations for Model Improvement and Future Work . . . 133

8. Summary and Outlook 135
8.1. Summary . . . 135

8.2. Outlook 138

References **141**

A. Appendix **XXI**

A.1. Additional Information on Residence Time Measurement XXI

A.2. Characterization of the Mass and Energy Balance of the Miniplant Used XXIV

A.3. Supplementary to Fluid Properties of Binary Mixtures XXVI

A.4. Declaration of generative AI and AI-assisted technologies in the writing process . . XL

A.5. List of Publications XL