Contents

Abstract v
Resumen vii
Resum ix
Acknowledgment xi
Contents xiii
List of Tables xvi
List of Figures xvii
Nomenclature xxiii
1. Introduction 29
1.1 Two-phase flow Numerical methods 29
1.2 Review for the past work 31
1.2.1 One-way coupling 31
1.2.2 Two-way coupling 31
1.2.2.1 Source terms in the momentum equation 32
1.2.2.2 Bubble induced turbulence effect 33
1.2.3 Four-way coupling 34
1.2.3.1 Collision modeling 34
1.2.3.2 Coalescence modeling 35
1.2.3.3 Breakup modeling 35
1.2.4 Works used stochastic modeling for bubbles diffusion. 36
1.3 Objectives of the present research 36
1.4 Experimental database 37
1.5 Thesis outline 44
2. Numerical modeling 47
2.1 Bubbles hydrodynamics 47
2.1.1 Acting forces 47
2.1.1.1 Indications of Forces for Different Cases 69
2.1.2 Collision modeling 72
2.1.3 Coalescence modeling 75

2.1.4 Breakup modeling 85
2.2. The Euler Solver Overview 95
2.2.1 Conservation Equations 95
2.2.2 Turbulence modeling 96
2.2.3 Control input file 98
2.3. The Lagrangian Solver Overview 99
2.3.1 Equation of motion 99
2.3.2 Methods for locating particles in elements of arbitrary shape 100
2.3.3 Algorithms for Locating particles 103
3. Turbulence modeling 107
3.1 Introduction 107
3.2 Turbulence modeling for the Euler solver 110
3.3 Stochastic modeling of particles diffusion 111
3.4 Bubbles induced turbulence (BIT) modeling 118
3.5 Indication for the CRW model including the BIT effect 122
4. One-way Coupling Process Study and Discussion 125
4.1 Approximating Eulerian quantities at bubble location 125
4.2 Computational domain and boundary conditions 127
4.3 Time stepping 128
4.4 Code algorithm 128
4.5 Study for the Effect of the BIT formula on the void fraction distribution. 130
4.6 Study for the Effect of the lift coefficient on the void fraction distribution. 137
4.7 Results and discussion 140
5. Two-way Coupling Process Study and Discussion 145
5.1 Two way coupling without considering bubbles interactions 145
5.1.1 Time stepping 145
5.1.2 Bubble data Interpolation at computational cells 146
5.1.3 Modifications in Euler solvers equations in the two-way coupling 150
5.1.3.1 Modification in momentum equations 150

5.1.3.2 Modification in turbulence equations 151
5.1.3.3 Source terms and density definition in the Euler solver 152
5.1.4 Code algorithm for two-way coupling without bubbles interactions 153
5.1.5 Results and discussion 157
5.1.5.1 Effect of Two-way coupling on liquid properties. 157
5.1.5.2 Effect of Two-way coupling on the gas phase. 160
5.1.5.3 Study of the Lift coefficient effect on the void profiles 162
5.2 Two way coupling with considering bubbles collision 164
5.2.1 Time stepping 165
5.2.2 Code algorithm 165
5.2.3 Results and Discussion 167
5.2.4 Study for the effect of the BIT coefficient on the void fraction distribution 168
5.2.5 Number of collisions density 180
5.2.6 Effect of gas holdup on turbulence data 184
5.2.7 Effect of considering bubbles coalescence 187
5.3 Two way coupling considering bubble's collision, coalescence and breakup 190
5.3.1 Time stepping 190
5.3.2 Code algorithm 190
5.3.3 Results and comparisons 192
5.4 Calculation time discussion 198
6. Conclusions and future work 201
6.1 Conclusions from the present work 201
6.1.1 One-way coupling 201
6.1.2 Two-way coupling 201
6.1.3 CRW model 202
6.1.4 New features in bubbly flow simulations 203
6.2 Future Work 204
Bibliography 205

Appendixes 221
Appendix A Acceleration Derivation in Cylindrical coordinates 221
Appendix B Data structure for the Lagrangian solver 224
B.1 Lagrangian variables 224
B.1.1 Data structure applied for bubbles coalescence 225
B.1.2 Data structure applied for bubbles breakup 226
B.2 Common data variables 226
Publications from the present research 227