Contents

1. Introduction .................................................. 1
   1.1. Background .................................................. 1
   1.2. Motivation and objectives .................................. 4
   1.3. Outline of the thesis ...................................... 7

2. Physical model ................................................. 9
   2.1. Bubble radial dynamics .................................... 9
   2.2. Wave propagation in bubbly liquids ...................... 18
      2.2.1. Derivation of the effective equations of the Caflisch model ....... 22
      2.2.2. Linear wave equation without bubbles ....................... 24
      2.2.3. Linearized wave equation in bubbly liquids- Linear attenuation .... 25
      2.2.4. Nonlinear attenuation of wave propagation ................... 26
   2.3. Lagrangian tracing of bubbles with varying radii ......... 39
      2.3.1. Flow field equations ................................... 40
      2.3.2. Acoustic streaming source term $F_{A.S.}$ .................... 42
      2.3.3. Lagrangian frame formulation ............................ 43
   2.4. Population of bubbles ...................................... 49

3. Numerical method .............................................. 53
   3.1. Numerical set-up for linear analysis ...................... 54
      3.1.1. Geometries, boundary conditions and physical properties .......... 54
      3.1.2. Procedure of the linear analysis .......................... 57
      3.1.3. Grid generation and grid study ............................ 58
   3.2. Numerical set-up for nonlinear analysis ................... 61
      3.2.1. Geometries, boundary conditions and physical properties .......... 65
      3.2.2. Procedure of the nonlinear analysis ........................ 68
4. Results: Linearized approximations

4.1. Simple geometries as benchmarks

4.1.1. Simulation of wave propagation

4.1.2. Simulation of acoustic streaming

4.2. Pressure distribution in conical reactor

4.2.1. Pressure distribution without attenuation due to bubbles

4.2.2. Pressure distribution for homogeneous distribution of bubbles

4.2.3. Pressure distribution for inhomogeneous distribution of bubbles

4.3. Flow field simulation in the conical reactor

5. Results: Nonlinear approximations

5.1. Benchmarks for numerical implementations

5.1.1. Backward Facing Step (BSF)

5.1.2. Sudden expansion: convection of a single bubble with varying radius in a sound field

5.2. Orders of magnitude of the forces on bubbles

5.3. One-dimensional simulation

5.3.1. Single bubble motion - Linear oscillations

5.3.2. Single bubble motion - Nonlinear oscillations and convection

5.4. Two-dimensional simulation

5.4.1. Single bubble motion - Linear oscillations

5.4.2. Multiple bubbles motion - Nonlinear oscillations

5.4.3. Multiple bubbles motion - Nonlinear damping

5.5. Three-dimensional simulation

6. Summary and recommendation for future work

A. Appendix

A.1. List of Tables

A.2. List of Figures

A.3. Nomenclature
B. Bibliography

C. Declaration

D. Curriculum Vitae