



Contents

1	Introduction and Objectives	1
2	Fundamentals	3
2.1	CFD in Stirred Tank Reactors - a Review	3
2.2	Governing Equations	9
2.2.1	Numerical Grid and Discretization	12
2.2.2	Boundary Conditions	17
2.2.3	Unsteady State Flows	18
2.3	Turbulence Modeling	20
2.3.1	General Approaches in Turbulence Modeling	21
2.3.2	Reynolds-Averaged Navier-Stokes Equations	22
2.3.3	RNG- k - ϵ Turbulence Model	24
2.3.4	Shear Stress Transport Turbulence Model	24
2.3.5	SSG Reynolds Stress Model	27
2.4	Multiphase Flows	28
2.4.1	Euler-Euler and Euler-Lagrange Approaches	29
2.4.2	Interfacial Momentum Transfer	31
2.5	Flow Behavior of Culture Media in Bioreactors	32
2.5.1	Rheology Models	33
2.5.2	Parameters Estimation	34
3	Results and Discussions	35
3.1	Numerical Characterization of Ideal Bioreactors	35
3.1.1	Simulation Specifications	35
3.1.2	Grid Dependency	37
3.1.3	Flow Patterns in Steady State Flow	42
3.1.4	Mechanical Stress in Steady State Flow	52
3.1.5	Flow Patterns in Unsteady State Flow	61
3.1.6	Mechanical Stress in Unsteady State Flow	65



3.2	Effect of non-Newtonian Flow Behavior on Flow Patterns	69
3.2.1	Flow Patterns of Cultivation Media	70
3.2.2	Effect of Flow Behavior of Cultivation Broth on Mechanical Stress .	75
3.3	Assessment of Binary Flows in Bioreactors	79
3.3.1	Simulation Specification	80
3.3.2	Flow patterns in Steady State Binary Flows	82
3.3.3	Quantification of Mechanical Stress in Binary Steady State Flows .	85
3.3.4	Effect of Time Dependency on Flow Patterns in Binary Flows . . .	91
3.3.5	Mechanical Stress in Unsteady State Binary Flows	93
3.4	Effect of Impeller Design	97
3.4.1	Simulation Specifications	98
3.4.2	Quantitative Comparison of Different Impellers	100
4	Conclusions and Future Prospects	105
5	Bibliography	108
6	Notation	123
6.1	Variables	123
6.2	Greek Symbols	125
6.3	Superscripts	126
6.4	Subscripts	126
6.5	Abbreviations	127