

Contents

Title Page	i
Certificate of Approval	v
Certificate	vii
Acknowledgements	ix
Declaration	xi
Contents	xiii
List of Symbols and Abbreviations	xvii
Abstract	xxi
Chapter 1 Introduction	1
1.1 Porous Media	1
1.2 Transport Phenomena	2
1.2.1 Momentum Transfer	2
1.2.2 Mass Transfer	3
1.2.3 Concentration Equation	3
1.3 Equation of Motion	4
1.3.1 Conservation of Mass (Equation of Continuity)	4
1.3.2 Viscous Flow	5
1.4 Boundary Conditions	10
1.5 Faxén's Laws	13
1.6 Fundamental Solutions	14
1.6.1 Steady Stokes Equation	14
1.6.2 Oscillatory Stokes Equation	15
1.7 Literature Review	16
1.8 Thesis Overview	23
Chapter 2 Faxén's Laws for Arbitrary Oscillatory Stokes Flow Past a Darcy Porous Sphere	29
2.1 Introduction	29

2.2	Mathematical Formulation	32
2.2.1	Governing Partial Differential Equations	32
2.2.2	Boundary Conditions	33
2.3	Method of Solution	34
2.4	Faxén's Laws for a Porous Sphere in Oscillatory Flow	38
2.4.1	Uniform Oscillatory Flow Past a Porous Sphere	42
2.4.2	Flow Due to an Oscillating Stokeslet	44
2.4.3	A Porous Sphere in a Linear Oscillatory Shear Flow	47
2.4.4	A Porous Sphere in a Quadratic Oscillatory Shear Flow	47
2.5	Results and Discussions	48
2.6	Conclusion	53
Chapter 3	Faxén's Laws for Arbitrary Oscillatory Stokes Flow Past a Brinkman Porous Sphere	55
3.1	Introduction	55
3.2	Mathematical Formulation	57
3.2.1	Governing Partial Differential Equations	57
3.2.2	Boundary Conditions	59
3.3	Method of Solution	61
3.4	Faxén's Laws for a Porous Sphere in Oscillatory Flow	63
3.4.1	Uniform Oscillatory Flow Past a Porous Sphere	64
3.4.2	Flow Due to an Oscillating Stokeslet	65
3.4.3	A Porous Sphere in a Linear Oscillatory Shear Flow	69
3.4.4	A Porous Sphere in a Quadratic Oscillatory Shear Flow	69
3.5	Results and Discussions	69
3.6	Conclusion	72
Chapter 4	Convection–Diffusion–Reaction Inside a Spherical Porous Pellet Under Oscillatory Flow–Dirichlet Condition	73
4.1	Introduction	73
4.2	Nutrient Transport Inside a Spherical Porous Pellet	77
4.2.1	Zero Order Reaction Case	77
4.2.2	First Order Reaction Case	81
4.3	Results and Discussions	83
4.3.1	Concentration Profiles	83
4.4	Conclusion	94
Chapter 5	Convection–Diffusion–Reaction Inside a Spherical Porous Pellet Under Oscillatory Flow–Robin Condition	97
5.1	Introduction	97
5.2	Nutrient Transport Inside a Spherical Porous Pellet	98
5.2.1	Zero Order Reaction Case	98

5.2.2	First Order Reaction Case	103
5.3	Results and Discussions	105
5.3.1	Concentration Profiles	105
5.4	Conclusion	112
Chapter 6	Dirichlet Problem for Convection–Diffusion–Reaction Inside a Permeable Cylindrical Porous Pellet	115
6.1	Introduction	115
6.2	Oscillatory Stokes Flow Past a Permeable Cylindrical Porous Pellet	117
6.2.1	Mathematical Formulation and Method of Solution	117
6.2.2	Boundary Conditions	120
6.3	Nutrient Transport Inside a Permeable Cylindrical Porous Pellet	122
6.3.1	Zero Order Reaction Case	122
6.3.2	First Order Reaction Case	124
6.4	Results and Discussions	125
6.4.1	Internal Velocity Profiles	126
6.4.2	Concentration Profiles	126
6.4.3	Comparison of Nutrient Transport Inside a Cylindrical Pellet Against a Spherical Pellet	132
6.5	Conclusion	135
Chapter 7	Expansions at Small Reynolds Numbers for the Flow Past a Porous Circular Cylinder	137
7.1	Introduction	137
7.2	Formulation of the Problem	140
7.3	Method of Solution	142
7.3.1	Inner Expansions	143
7.3.2	Outer Expansions	143
7.3.3	Leading Order Terms	144
7.3.4	First Order Terms	147
7.4	Higher Order Terms in the Stokes and Oseen Expansions	151
7.5	Drag on the Surface of the Porous Circular Cylinder	152
7.6	Porous Circular Cylinder with Darcy’s Flow	153
7.7	Porous Circular Cylinder with a Rigid Core	155
7.8	Results and Discussions	158
7.9	Conclusion	160
Chapter 8	Overall Bed Permeability for Flow Through Beds of Permeable Porous Particles	163
8.1	Introduction	163

8.2 Cell Model	166
8.2.1 Assemblage of Porous Spheres Using Brinkman Equation	166
8.2.2 Boundary Conditions	168
8.2.3 Drag Force Acting on the Surface of the Representative Porous Sphere	170
8.2.4 Overall Bed Permeability (OBP)	172
8.2.5 Some Existing Limiting Cases	173
8.3 Effective Medium Model	175
8.3.1 Mathematical Formulation and Method of Solution . . .	175
8.3.2 Boundary Conditions	177
8.3.3 Faxén's Laws for Drag and Torque Acting on the Surface of Permeable Porous Sphere	179
8.3.4 Uniform Flow	180
8.3.5 Overall Bed Permeability (OBP)	180
8.4 Results and Discussions	182
8.4.1 Cell Model	182
8.4.2 Effective Medium Model	187
8.5 Conclusion	193
Chapter 9 Summary, Conclusions and Future Scope of Study	195
9.1 Contribution of Thesis	197
9.2 Future Scope of Study	198
Bibliography	199
List of Publications	213