
Contents

Declaration	i
Certificate	iii
Abstract	vii
Acknowledgements	xi
List of Figures	xvi
List of Tables	xx
1 General Introduction	1
1.1 SOME BASIC PROPERTIES	2
1.2 CLASSIFICATION OF FLUIDS	3
1.3 TYPES OF FLOW	4
1.4 HEAT TRANSFER	5
1.5 MASS TRANSFER	6
1.6 MAGNETOHYDRODYNAMICS	7
1.7 POROUS MEDIUM	9
1.8 BASIC EQUATIONS	10
1.9 BOUNDARY LAYER	11
1.10 PHYSICAL QUANTITIES	13
1.11 NON-DIMENSIONAL QUANTITIES	14
1.12 NANOFUIDS	16
1.13 METHODOLOGY	18

1.14	STATISTICAL ANALYSIS	20
1.15	OBJECTIVES	22
1.16	REVIEW OF RELEVANT LITERATURE	22
2	MHD Nanofluid Flow Between Two Vertical Porous Plates Moving In Opposite Direction	37
2.1	INTRODUCTION	37
2.2	MATHEMATICAL FORMULATION	38
2.3	METHOD OF SOLUTION	42
2.4	PHYSICAL QUANTITIES	47
2.5	RESULTS AND DISCUSSION	48
2.6	STATISTICAL ANALYSIS	50
2.7	CONCLUSION	51
3	Three-dimensional MHD Hybrid Nanofluid Flow Between Two Vertical Porous Plates Moving In Opposite Directions	67
3.1	INTRODUCTION	67
3.2	MATHEMATICAL FORMULATION	68
3.3	METHOD OF SOLUTION	72
3.4	PHYSICAL QUANTITIES	76
3.5	RESULTS AND DISCUSSION	77
3.6	STATISTICAL ANALYSIS	78
3.7	CONCLUSION	80
4	Bioconvective EMHD Hybrid Nanofluid Flow Past a Stretching Sheet	97
4.1	INTRODUCTION	97
4.2	MATHEMATICAL FORMULATION	97
4.3	PHYSICAL QUANTITIES	100
4.4	NUMERICAL PROCEDURE AND VALIDATION	101
4.5	RESULTS AND DISCUSSION	102
4.6	STATISTICAL ANALYSIS	104
4.7	CONCLUSION	106
5	Bioconvective MHD Hybrid Nanofluid Flow past an Exponential	

Stretching Sheet	127
5.1 INTRODUCTION	127
5.2 MATHEMATICAL FORMULATION	128
5.3 PHYSICAL QUANTITIES	131
5.4 NUMERICAL PROCEDURE	131
5.5 RESULTS AND DISCUSSION	132
5.6 STATISTICAL ANALYSIS	134
5.7 CONCLUSION	136
6 Conclusion	157
Publications in Journals and Presentations	161
Bibliography	163
References	163

List of Figures

1.1	Velocity boundary layer development on a flat plate	11
1.2	Thermal boundary layer development on a flat plate	12
1.3	Concentration boundary layer development on a flat plate	13
2.1	Physical configuration	38
2.2	Variation in u with Gr	54
2.3	Variation in u with Gm	54
2.4	Variation in u with H at $y = 0$	55
2.5	Variation in u with H at $y = 1$	55
2.6	Variation in u with Re at $y = 0$	56
2.7	Variation in u with Re at $y = 1$	56
2.8	Variation in u with ϕ	57
2.9	Variation in u with different nanofluids	57
2.10	Variation in θ with ϕ	58
2.11	Variation in θ with Re	58
2.12	Variation in C with Sc	59
2.13	Variation in Cf with Re and ϕ at $y = 0$	59
2.14	Variation in Cf with Re and ϕ at $y = 1$	60
2.15	Variation in Cf with Gr and H at $y = 0$	60
2.16	Variation in Cf with Gr and H at $y = 1$	61

2.17	Actual Nu versus estimated Nu	61
2.18	Actual Sh versus estimated Sh	62
3.1	Physical configuration	68
3.2	Variation in u with Gr	85
3.3	Variation in u with H	85
3.4	Variation in u with ϕ_1	86
3.5	Variation in u with ϕ_2	86
3.6	Variation in u with Re	87
3.7	Variation in θ with ϕ_1	87
3.8	Variation in θ with ϕ_2	88
3.9	Variation in θ with Re	88
3.10	Variation in Cf with ϕ_1 and Re at $y = 0$	89
3.11	Variation in Cf with ϕ_1 and Re at $y = 1$	89
3.12	Variation in Cf with Gr and H at $y = 0$	90
3.13	Variation in Cf with Gr and H at $y = 1$	90
3.14	Residual plots	91
3.15	Contour and surface plots for Nu	92
3.16	Bar charts depicting the sensitivity of Nu	93
4.1	Physical configuration	98
4.2	Variation in $f'(\eta)$ with H when $E = 0$	113
4.3	Variation in $f'(\eta)$ with H when $E \neq 0$	113
4.4	Variation in $f'(\eta)$ with E	114
4.5	Variation in $\theta(\eta)$ with S_1	114
4.6	Variation in $\theta(\eta)$ with Ec	115
4.7	Variation in $\theta(\eta)$ with ϕ_1	115
4.8	Variation in $\theta(\eta)$ with ϕ_2	116
4.9	Variation in $\psi(\eta)$ with K_c	116
4.10	Variation in $\psi(\eta)$ with S_2	117
4.11	Variation in $\chi(\eta)$ with S_3	117
4.12	Variation in $Cf_x Re_x^{1/2}$ with ϕ_1 and E	118
4.13	Variation in $Cf_x Re_x^{1/2}$ with ϕ_2 and M	118
4.14	Variation in $Nu_x Re_x^{-1/2}$ with ϕ_2 and Ec	119

4.15	Variation in $Nu_x Re_x^{-1/2}$ with ϕ_2 and S_1	119
4.16	Residual versus fitted value of Cf_{SWCNT}	120
4.17	Residual versus fitted value of Cf_{MWCNT}	121
4.18	Surface plots Cf_{SWCNT}	122
4.19	Surface plots Cf_{MWCNT}	123
5.1	Physical configuration	128
5.2	Variation in $f'(\eta)$ with M	142
5.3	Variation in $f'(\eta)$ with K_p	143
5.4	Variation in $f'(\eta)$ with S	143
5.5	Variation in $\theta(\eta)$ with M	144
5.6	Variation in $\theta(\eta)$ with R	144
5.7	Variation in $\theta(\eta)$ with Ec	145
5.8	Variation in $\theta(\eta)$ with β	145
5.9	Variation in $\theta(\eta)$ with K_p	146
5.10	Variation in $\theta(\eta)$ with S	146
5.11	Variation in $\theta(\eta)$ with ϕ_1	147
5.12	Variation in $\theta(\eta)$ with ϕ_2	147
5.13	Variation in $\psi(\eta)$ with M	148
5.14	Variation in $\psi(\eta)$ with K_c	148
5.15	Variation in $\psi(\eta)$ with S	149
5.16	Variation in $\psi(\eta)$ with Le	149
5.17	Variation in $\chi(\eta)$ with M	150
5.18	Variation in $\chi(\eta)$ with K_p	150
5.19	Variation in $\chi(\eta)$ with Pe	151
5.20	Variation in $\chi(\eta)$ with Lb	151
5.21	Variation in $\chi(\eta)$ with Ω	152
5.22	Variation in $Sh_x Re_x^{-1/2}$ with K_c and S	152
5.23	Variation in $Sh_x Re_x^{-1/2}$ with K_p and ϕ_1	153
5.24	Actual versus estimated $Cf_x Re_x^{1/2}$	153
5.25	Actual versus estimated $Nu_x Re_x^{-1/2}$	154

List of Tables

2.1	Thermophysical properties of base fluid and nanoparticles	52
2.2	Variation in Nu for differing parameter values at $y = 1$ when $\phi = 0.02, \omega = 5, Re = 1, t = \pi/2, z = 0$ and $Pr = 7$	52
2.3	Variation in Sh for differing parameter values at $y = 1$ when $\omega = 5, Re = 1, Sc = 0.2, Kr = 1, t = \pi/2, z = 0$ and $Pr = 7$	53
2.4	Correlation coefficient (r), Probable error (PE) and $ \frac{r}{PE} $ values of Nu at $y = 1$ with respect to the parameters ϕ, ω, Re and t	53
2.5	Correlation coefficient (r), Probable error (PE) and $ \frac{r}{PE} $ values of Sh at $y = 1$ with respect to the parameters ω, Re, Sc, Kr and t	53
3.1	Physical properties of nanoparticles and base fluid	81
3.2	Comparison of Nu with augmenting Re values when $\phi_1 = 0, \phi_2 = 0, \Omega = 10, t = \pi/2, Pr = 7, Gr = 5$ and $H = 2$	81
3.3	Effective parameter levels	81
3.4	Experimental design with response	82
3.5	ANOVA table	83
3.6	Sensitivity of response Nu when $A = 0$	84
4.1	Comparison of $Nu_x Re_x^{-1/2}$ for differing Pr values when $H = E = K_c = Ec = Le = Lb = Pe = \Omega = S_1 = S_2 = S_3 = 0$	107
4.2	Thermophysical properties	108

4.3	Comparison of $Sh_x Re_x^{-1/2}$ for differing H, E, K_c , and S_2 values when $Le = 2, Lb = 1.2, Ec = 0.3, \Omega = Pe = 0.5, S_1 = S_3 = \phi_1 = \phi_2 = 0.1$ and $Pr = 6.2$	108
4.4	Comparison of $Nn_x Re_x^{-1/2}$ for differing H, E, K_c , and S_3 values when $Le = 2, Lb = 1.2, Ec = 0.3, \Omega = Pe = 0.5, S_1 = S_2 = \phi_1 = \phi_2 = 0.1$ and $Pr = 6.2$	109
4.5	Effectual parameter levels	109
4.6	Four-factor CCD experimental design and the corresponding responses	110
4.7	ANOVA table (Cf_{SWCNT}).	111
4.8	ANOVA table (Cf_{MWCNT})	112
5.1	Comparison of $-\theta'(0)$ for different values of Pr when $\phi_1 = \phi_2 = M =$ $R = Ec = Le = Lb = K_c = K_p = \beta = \Omega = Pe = S = 0$	137
5.2	Thermophysical properties	138
5.3	Variation in $Cf_x Re_x^{1/2}$ when $Pr = 6.2, R = 1, Ec = 0.3, Le = 2, K_c =$ $\Omega = Pe = 0.5, \beta = 0.1$, and $Lb = 1.2$	138
5.4	Variation in $Cf_x Re_x^{1/2}$ when $Pr = 6.2, R = 1, Ec = 0.3, Le = 2, K_c =$ $\Omega = Pe = 0.5, \beta = 0.1$, and $Lb = 1.2$	139
5.5	Variation in $Nu_x Re_x^{-1/2}$ when $Pr = 6.2, Le = 2, K_c = \Omega = Pe =$ $0.5, K_p = 1, Lb = 1.2$ and $S = 0.1$	140
5.6	Variation in $Nn_x Re_x^{-1/2}$ when $Pr = 6.2, H = R = 1, S = \beta = \phi_1 =$ $\phi_2 = 0.1$, and $Ec = 0.3$	141
5.7	Correlation coefficient (r), probable error (PE), and $\left \frac{r}{PE} \right $ values of $Cf_x Re_x^{1/2}$	141
5.8	Correlation coefficient (r), probable error (PE), and $\left \frac{r}{PE} \right $ values of $Nu_x Re_x^{-1/2}$	142