

TABLE OF CONTENTS

Declaration by the Candidate	iii
Acknowledgement	v
List of Figures.....	vi
List of tables.....	ix
Abbreviations	x
Abstract.....	xvi
1 Introduction	1
1.1 Introduction	1
1.2 Need of electronics cooling.....	1
2 Literature Review.....	4
2.1 Cooling methods used in practice	4
2.2 Jet cooling Techniques	6
2.3 Jet impingement review	8
2.3.1 Jets related to flow	8
2.3.2 Jets related to physical structure of cooling system.....	10
2.3.3 Jets based on fluid used for cooling.....	11
2.3.4 Synthetic jets.....	14
2.3.5 Exit Jet shapes.....	15
2.3.6 Jets with varied impingement frequency	17
2.3.7 Jets depending on surface characteristics	17
2.3.8 Inclined jets.....	18
2.3.9 Other cases of jets	19
2.3.10 Summary	20
2.4 Review on inclined Jet	23
2.4.1 Literature on inclined jet.....	23

2.4.2	Summary	28
2.5	Gap analysis	31
2.6	Objective and scope	32
2.7	Conclusion.....	32
3	Governing equations of inclined jet flow.....	33
3.1	Introduction	33
3.2	Terminology of inclined jet.....	33
3.3	Velocity profile of inclined jet	36
3.4	Basic equations of inclined jet flow	38
3.5	Dimensional Analysis	44
3.6	Conclusion.....	46
4	Methodology and Experimental Setup.....	47
4.1	Introduction	47
4.2	Heat transfer calculations	47
4.3	Description of Experimental setup.....	49
4.4	Setup equipment specification	55
4.5	Validation of experimental setup	56
4.6	Conclusion.....	58
5	Nusselt Number - Results and discussion.....	59
5.1	Introduction	59
5.2	Nusselt Number distribution	59
5.2.1	Effect of variation in Reynolds Number	59
5.2.2	Effect of variation of (H/D)	60
5.2.3	Effect of variation of inclination.....	61
5.3	Average Nusselt Number	62
5.3.1	Average Nusselt Number for angle of impingement	63

5.3.2	Average Nusselt Number for specific inclined jet diameter	64
5.3.3	Average Nusselt Number with Inclined jet to target Distance	67
5.3.4	Average Nusselt Number with H and AR - for entire range of investigation	68
5.3.5	Average Nusselt Number related to (Xo/D)	70
5.4	Maximum Nusselt Number	71
5.4.1	Maximum Nusselt Number as per angle of impingement	71
5.4.2	Maximum Nusselt Number with reference to H/D.....	74
5.4.3	Maximum Nusselt Number related to height of Jet to target (H)	75
5.4.4	Maximum Nusselt Number correlations	76
5.4.5	Maximum Nusselt Number related with (Xo/D)	79
5.4.6	(Nu _{avg} / Nu _{max}) analysis.....	80
5.5	Position of Maximum Nusselt Number.....	81
5.5.1	Position of Maximum Nusselt Number - inclination wise.....	82
5.5.2	Location of Maximum Nusselt Number w.r.t. Reynolds Number, angle ratio and target to jet height.....	83
5.5.3	Position of maximum Nusselt Number with variation of inclination	85
5.6	Conclusion.....	86
6	Temperature Study and Enhancement – Result and Discussion.....	88
6.1	Introduction	88
6.2	Center line temperature analysis (For D=16mm).....	88
6.2.1	Temperature ratio for different jet impingement angles with H=40mm	89
6.2.2	Temperature ratio for all heights, w.r.t. jet impingement angles	89
6.2.3	Temperature ratio for all angles w.r.t. variation in target to jet height	.90
6.2.4	(T _{min} - T _o / T _c - T _o) variation related to Reynolds Number.....	91
6.2.5	(T _{min} /T _c) at specific jet inclinations of 15, 45 and 75 Degree	92

6.3	Temperature profile / cold spot of a target surface	93
6.3.1	Effect of Reynolds Number on temperature profile	93
6.3.2	Influence of target to jet height on temperature profile	95
6.3.3	Influence of jet inclination angle on temperature profile.....	95
6.4	The Enhancement Factor (EF)	98
6.4.1	Definition and concept.....	98
6.4.2	EF for overall range of experimentation	98
6.4.3	EF variation w.r.t. target to jet height (H).....	100
6.4.4	EF on jet inclination basis.....	101
6.4.5	EF on basis of Reynolds Number	103
6.5	Optimization using Multiple Attribute Decision Making	106
6.6	Conclusion.....	107
7	Conclusions and future scope.....	108
7.1	Conclusions	108
7.2	Future scope	110
	References	111
	Appendix I – Dimensional Analysis	120
	Appendix II – Data Tables associated to experimentation.....	124
	Appendix III – Thermal Images	126
	Appendix IV -Uncertainty Analysis	127
	Appendix V – Experimental setup photographs	131
	Appendix VI – Observation and Calculation tables	132
	Publications	178