# LIST OF FIGURES

1.1 Boundary layer on flat plate 3
1.2 Schematic diagram of a modern gas turbine blade with common internal cooling techniques 7
2.1 The test section used for study by Syred et al. 13
2.2 Variation of average Stanton number in a flat, concave and convex Dimple 13
2.3 Relative Stanton number: 1. Concave wall 2. Convex wall curves 14
2.4 Pictorial representation of average heat transfer rate for various configurations at \( \delta^{**}/R=2 \times 10^{-3} \), \( \text{Re}_{Dh}=8 \times 10^4 \) 14
2.5 Comparison of the patterns of flow spreading on the wall of a narrow plane-parallel channel in the neighborhood of a spherical dimple of variable depth 16
2.6 The heat transfer characteristics with different dimple depth Curve (1) for dimple surface Curve (2) for wake region 17
2.7 Test plate used by Ligrani P.M.et al. 22
2.8 The flow structure obtained by Ligrani P.M.et al. 22
3.1 Schematic diagram of experimental setup 30
3.2 Photograph of experimental setup 30
3.3 Photograph of orifice with U tube manometer 31
3.4 Photograph of blower 31
3.5 Enlarged cross-sectional view of test 35
3.6 Schematic diagram of dimple surface 35
3.7 Top view of test surface (a) Flat plate (b) Dimple depth \( \delta/D=0.2 \) (c) Dimple depth \( \delta/D=0.3 \) (d) Dimple depth \( \delta/D=0.4 \) 36
3.8 Thermocouple locations on test plate 37
3.9 Exit chamber consist of mixing device 37
3.10 Photograph of control panel 40
3.11 Photograph of micromanometer 40
3.12 Heat loss estimation based on base surface temperature 44
3.13 Mechanism of heat transfer for flat channel 44
4.1 Comparison of heat transfer characteristics for flat channel 48
4.2 Comparison of Nu/Nu₀ with Isaev et al. 48
4.3 Comparison of friction factor with correlation for flat duct 49
4.4 Predicted flow structure for dimple depth δ/D=0.2 51
4.5 Predicted flow structure for dimple depth δ/D=0.3 51
4.6 Predicted flow structure for dimple depth δ/D=0.4 52
4.7 Nu as a function of Re_Dh for
(a) Q_in=25 W (b) Q_in=50 W 55
(c) Q_in =60 W (d) Q_in=75 W 56
4.8 Nu/Nu₀ as a function of Re_Dh for
(a) Q_in =25 W (b) Q_in =50 W 57
(c) Q_in =60 W (d) Q_in=75 W 58
4.9 Variation of f as a function of Re_Dh 61
4.10 Variation of f/f₀ as a function of Re_Dh 61
4.11 Effect of dimple depth on Nu/Nu₀ for
(a) Q_in =25 W (b) Q_in =50 W 64
(c) Q_in =60 W (d) Q_in=75 W 65
4.12 Effect of dimple depth on f/f₀ 66
4.13 Comparison of Nu/Nu₀ as a function of f/f₀ at different Dimple Depth
for (a) Q_in =25 W (b) Q_in =50 W 69
(c) Q_in =60 W (d) Q_in=75 W 70
4.14 Nu/Nu₀ as a function of T_α/T_w at different Re_Dh for δ/D=0.3 71
4.15 η_th as a function of Re_Dh for
(a) Q_in =25 W (b) Q_in =50 W 73
(c) Q_in =60 W (d) Q_in=75 W 74
4.16 Effect of δ/D on η_th for
(a) Q_in =25 W (b) Q_in =50 W 75
(c) Q_in =60 W (d) Q_in=75 W 76
4.17 Variation of Nu vs Re_Dh 79
4.18 Variation of Nu/Re_Dh^{0.9256} vs δ/Dh 79
4.19 Variation of experimental values vs predicted values of Nu 80
4.20 Variation of f vs Re_Dh 81
4.21 Variation of f/ Re_Dh^{-0.1392} vs Re_Dh 81
4.22 Variation of experimental values vs predicted values of f’ 82
5.1 Geometric model created in gambit 89
5.2 Mesh used for CFD analysis 89
5.3 The five different sets of grids for grid independent study 91
5.4 Finalizing the grid cell count 92
5.5 Validation of turbulence model at $Q_{in}=75$ W 94
5.6 Monitor for the scaled residuals 96
5.7 Monitor for temperature 96
6.1 Schematic diagram of planes used for computation of the flow structure 99
6.2 Velocity vectors before the dimple on symmetry plane 100
6.3 Velocity vectors at the leading edge of dimple on symmetry plane 100
6.4 Velocity vectors at the trailing edge of dimple on symmetry plane 101
6.5 Velocity vectors at $X/Dh=1.25$ 101
6.6 Velocity vectors at $X/Dh=1.1875$ 102
6.7 Streamlines for
(a) Flat plate (b) $\delta/D=0.2$ 103
(c) $\delta/D=0.3$ (d) $\delta/D=0.4$ 104
6.8 u-velocity contours in spanwise normal plane at $X/Dh=1.25$
(a) $\delta/D=0.2$ (b) $\delta/D=0.3$ 107
(c) $\delta/D=0.4$ 108
6.9 u-velocity contours in spanwise normal plane at $X/Dh=1.25$ for
(a) $\delta/D=0.2$ 108
(b) $\delta/D=0.3$ (c) $\delta/D=0.4$ 109
6.10 v-velocity contours in spanwise normal plane at $X/Dh=1.25$ for
(a) $\delta/D=0.2$ (b) $\delta/D=0.3$ 111
(c) $\delta/D=0.4$ 111
6.11 v-velocity contours in spanwise normal plane at $X/Dh=1.875$ for
(a) $\delta/D=0.2$ 115
(b) $\delta/D=0.3$ (c) $\delta/D=0.4$ 112
6.12 w-velocity in spanwise normal plane at $X/Dh=1.25$ for
(a) $\delta/D=0.2$ (b) $\delta/D=0.3$ 113
(c) $\delta/D=0.4$ 114
6.13 w-velocity contours in spanwise normal plane at $X/Dh=1.875$ for
(a) $\delta/D=0.2$ 114
(b) $\delta/D=0.3$ (c) $\delta/D=0.4$ 115
6.14 Normalized streamwise vorticity in spanwise normal plane at X/Dh=1.25
   (a) δ/D=0.2 (b) δ/D=0.3
   (c) δ/D=0.4

6.15 Normalized streamwise vorticity in spanwise normal plane at X/Dh =1.825 for
   (a) δ/D=0.2
   (b) δ/D=0.3 (c) δ/D=0.4

6.16 Variation of du/dz along streamwise isoline on symmetry for
   (a) Flat plate (b) δ/D=0.2
   (c) δ/D=0.3 (d) δ/D=0.4

6.17 Variation of shear stress along streamwise isoline on symmetry for
   (a) δ/D=0.2 (b) δ/D=0.3
   (c) δ/D=0.4

6.18 Temperature contours for Re_Dh = 20000 at Q_in=75 for
   (a) Flat plate (b) δ/D=0.2
   (c) δ/D=0.3 (d) δ/D=0.4

6.19 Temperature plot for Re_Dh = 20000 at Y/D=0.16 at Q_in=75 for
   (a) Flat plate (b) δ/D=0.2
   (c) δ/D=0.3 (d) δ/D=0.4

6.20 Variation of Nu and Nu_n for flat plate
   (a) Q_in = 25 W (b) Q_in =50 W
   (c) Q_in =60 W (d) Q_in =75 W

6.21 Variation of Nu and Nu_n for δ/D=0.2 at
   (a) Q_in = 25 W (b) Q_in =50 W
   (c) Q_in =60 W (d) Q_in =75 W

6.22 Variation of Nu and Nu_n for δ/D=0.3 at
   (a) Q_in = 25 W (b) Q_in =50 W
   (c) Q_in =60 W (d) Q_in =75 W

6.23 Variation of Nu and Nu_n for δ/D=0.4 at
   (a) Qin = 25 W (b) Qin =50 W
   (c) Qin =60 W (d) Qin =75 W

6.24 Variation of f and f_n for at
   (a) Flat plate (b) δ/D=0.2
   (c) δ/D=0.3 (c) δ/D=0.4
7.1 Top and side view of Inverted U turbulator geometry
(a) 45° curved inverted U turbulator 143
(b) 60° curved inverted U turbulator 143
(c) 90° curved inverted U turbulator 143
(d) Straight inverted U turbulator 143

7.2 (a) Details of straight inverted U turbulator geometry 144
(b) Details of curved inverted U turbulator placed on test plate geometry 144

7.3 Photograph of inverted U turbulator geometry
(a) 45° inverted U turbulator (b) 60° inverted U turbulator 145
(c) 90° inverted U turbulator (d) Straight inverted U turbulator 145

7.4 Nu as a function of Re_{Dh} for different inverted U turbulator 147

7.5 Nu/Nu_0 as a function of Re_{Dh} for different inverted U turbulator 147

7.6 Variation of f as a function of Re_{Dh} for different inverted U turbulator 149

7.7 Variation of f/f_0 as a function of Re_{Dh} for different inverted U turbulator 149

7.8 Variation of η_{th} as a function of Re_{Dh} for different inverted U turbulator 150