

UNIVERSITY OF OTTAWA
OTTAWA-CARLETON INSTITUTE FOR MECHANICAL AND AEROSPACE
ENGINEERING ¹

**Effect of Transverse Convex Curvature on
Heat Transfer from Uniformly Heated
Surface with Backward-Facing Steps**

A thesis submitted in partial fulfillment of the requirements for
the degree of *Master of Applied Science (M.A.Sc.)*
in *Mechanical Engineering*

©Mossadeg Saadat NIAKI
University of Ottawa
Ottawa, Canada, K1N 6N5
March 1995

¹A joint graduate program of the University of Ottawa and Carleton University



National Library
of Canada

Acquisitions and
Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale
du Canada

Direction des acquisitions et
des services bibliographiques

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file *Voire référence*

Our file *Notre référence*

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-612-15750-4

Canada



UNIVERSITÉ D'OTTAWA
UNIVERSITY OF OTTAWA

Abstract

Local heat transfer coefficients have been obtained through measuring the temperature distribution along the separating, reattaching, and redeveloping regions of axisymmetric turbulent boundary layers on the wall of cylinders with constant heat flux. Measurements have been made with different configuration of three cylinders and five ellipsoidal steps on the leading face. The velocity of the turbulent flow was changed stepwise from 5 to 30 *m/s*. The range of Reynolds number, based on either the step height or diameter of convex curvature, is between 4,000 and 100,000.

In addition, a surface-stream-line flow visualization technique was tried to identify the reattachment loci, as well as the axisymmetry of the temperature distribution. It was found that the points of maximum heat transfer and reattachment are coincident within an uncertainty of ± 0.5 inch.

As a common feature, the rate of heat transfer undergoes a drop within a short length distance right after separation, followed by a rise leading to a sharp maximum at the reattachment neighborhood.

The study demonstrates that the maximum Nusselt number and heat transfer rate increase with either decreasing cylinder radius, or increasing

step diameter. The effect of step height is similar to that of the step diameter.

An empirical equation, correlated as a function of Reynolds number and aspect ratio of cylinder-step diameters, is proposed for the maximum Nusselt number.

Acknowledgements

I would like to acknowledge my appreciation to professor Yung Lee for his guidance and encouragement in course of advancement in present study.

The invaluable contribution of Dr. K.C. Kim, from Pusan National University(Korea), in offering his experience for modifying the design of the test tubes is also appreciated.

It is also my pleasure to extend thanks to the staff of machine shop for their technical assistance and workmanship on machining, repair, and modification of the test assembly and wind tunnel.

Contents

| | |
|--|--------------|
| Abstract | iii |
| Acknowledgements | v |
| List of Tables | xi |
| List of Figures | xxiii |
| Nomenclature | xxv |
| 1 Introduction | 1 |
| 1.1 Some Theoretical Aspects of Fluid | |
| Dynamics | 2 |
| 1.1.1 Turbulent Boundary Layer along Circular Cylinders . . | 2 |
| 1.1.2 Flow Species and Model Geometries in Backward-Facing | |
| Step Flow Separation | 3 |
| 1.1.3 Physics of Heat Transfer in a Turbulent Boundary Layer | 4 |

| | | |
|----------|---|-----------|
| 1.2 | Background Study | 5 |
| 1.2.1 | Effect of Transverse Convex Curvature on Heat Transfer | 5 |
| 1.2.2 | Effect of a Backward-Facing Step | 7 |
| 1.2.3 | Distinction Between the Points of Reattachment and Maximum Heat Transfer | 10 |
| 1.2.4 | A Conclusion to the Background Study | 12 |
| 1.3 | Objective | 14 |
| 2 | Experimental Apparatus and Instruments | 15 |
| 2.1 | Apparatus | 15 |
| 2.1.1 | Wind Tunnel | 16 |
| 2.1.2 | Test Assembly: the Cylinder and the Step | 16 |
| 2.2 | Instrumentation and Data Acquisition | 21 |
| 2.2.1 | Measurement of Velocity | 21 |
| 2.2.2 | Measurement of Temperatures | 22 |
| 2.2.3 | Heat Flux | 23 |
| 3 | Experimental Procedure | 26 |
| 3.1 | Commissioning of the Experimental Apparatus | 27 |
| 3.2 | Measurement of Velocity | 27 |
| 3.3 | Measurement of Wall Temperature Distribution | 28 |
| 3.4 | Flow Visualization | 29 |

| | | |
|----------|---|-----------|
| 4 | Data Reduction | 31 |
| 4.1 | Cylinder-Step Case Study | 31 |
| 4.2 | Axial Conduction Heat Transfer Rate | 32 |
| 4.3 | Local Heat Transfer Parameters | 33 |
| 4.4 | Correlation of Peak Heat Transfer Rate | 35 |
| 5 | Results and Discussion | 36 |
| 5.1 | General Features and Classification | 37 |
| 5.2 | Effect of Each Single Geometric Parameter | 39 |
| 5.2.1 | Effect of Transverse Convex Curvature | 39 |
| 5.2.2 | Effects of Height and Diameter of the Step | 42 |
| 5.2.3 | Effects of Aspect Ratio (D/d) | 43 |
| 5.3 | Entrainment and Correlation of the Effective Parameters | 43 |
| 5.4 | Flow Visualization | 45 |
| 5.4.1 | Application of the Technique | 45 |
| 5.4.2 | Points of Reattachment (X_r) and Maximum Heat Transfer (X_{max}) | 47 |
| 5.5 | Axial Conduction Heat Transfer | 49 |
| 6 | Conclusion | 51 |
| | References | 54 |

| | | |
|----------|---|------------|
| A | Tables of Data and Results | 60 |
| A.a | Overall Data and Results for All of the 7 Cases | 60 |
| A.a-i | Data and Results for 0.5" cylinder in Different Velocities; $S = 1"$ | 61 |
| A.a-ii | Data and Results for 0.5" cylinder in Different Velocities; $D = 4"$ | 70 |
| A.a-iii | Data and Results for 1" cylinder in Different Velocities; $S = 0.5"$ | 79 |
| A.a-iv | Data and Results for 1" cylinder in Different Velocities; $S = 1"$ | 96 |
| A.a-v | Data and Results for 1" cylinder in Different Velocities; $S = 1.5"$, $D = 4"$ | 113 |
| A.a-vi | Data and Results for 1" cylinder in Different Velocities; $S = 2"$ | 130 |
| A.a-vii | Data and Results for 2" cylinder in Different Velocities; $S = 1"$, $D = 4"$ | 147 |
| A.b | Data and Results at the Points of Maximum Heat Transfer, in Different Velocities, and for each of the 7 Cases | 164 |
| A.c | Tables of X_r , X_{max} , and $cond_{max}$ % for 7 cases, at $U = 7.5, 15,$ and 30 m/s | 172 |
| B | Set of Figures | 175 |
| C | Error Analysis | 184 |
| D | Technical Keywords | 189 |

| | |
|--|------------|
| E Computer Programs | 190 |
| E.1 Measurement of Wall Temperature and Free Stream Velocity | 190 |
| E.2 "TW FORTRAN", the Main Data Processor | 198 |
| E.3 Sample of a Data File | 201 |

List of Tables

| | | |
|-----|--|-----------|
| 2.1 | Measurements of the test cylinders | 19 |
| 2.2 | The configuration of thermocouple probes along the wall of the cylinders | 20 |
| 3.1 | Example of the velocity change order, case of $d = 2''$, $S = 1''$ | 28 |
| 5.1 | Variation of Reynolds numbers based on different Length Scales | 38 |
| 5.2 | Categories of Study based on Cylinder-Step Configuration . | 39 |
| | A.a: Overall Data and Results for All of the 7 Cases | 60 |
| | A.a-i: Data and Results for 0.5" Cylinder at Different Velocities; $S = 1''$ | 61 |
| A.1 | .5 in. cylinder with $S=1$ in.; $U = 30.1(m/s)$, $T = 23.6(^{\circ}C)$, $q = 1791(W/m^2)$, $i = 58.0(A)$ | 62 |
| A.2 | .5 in. cylinder with $S=1$ in.; $U = 30.1(m/s)$, $T = 23.8(^{\circ}C)$, $q = 1792(W/m^2)$, $i = 58.0(A)$ | 62 |
| A.3 | .5 in. cylinder with $S=1$ in.; $U = 27.3(m/s)$, $T = 23.3(^{\circ}C)$, $q = 1512(W/m^2)$, $i = 53.3(A)$ | 63 |

| | | |
|------|--|----|
| A.4 | .5 in. cylinder with $S=1$ in.; $U = 24.9(m/s)$, $T = 23.3(^{\circ}C)$, $q = 1436(W/m^2)$, $i = 52.0(A)$ | 63 |
| A.5 | .5 in. cylinder with $S=1$ in.; $U = 22.6(m/s)$, $T = 23.3(^{\circ}C)$, $q = 1443(W/m^2)$, $i = 52.0(A)$ | 64 |
| A.6 | .5 in. cylinder with $S=1$ in.; $U = 19.9(m/s)$, $T = 23.0(^{\circ}C)$, $q = 1229(W/m^2)$, $i = 48.0(A)$ | 64 |
| A.7 | .5 in. cylinder with $S=1$ in.; $U = 17.5(m/s)$, $T = 23.1(^{\circ}C)$, $q = 1138(W/m^2)$, $i = 46.3(A)$ | 65 |
| A.8 | .5 in. cylinder with $S=1$ in.; $U = 14.9(m/s)$, $T = 23.9(^{\circ}C)$, $q = 1029(W/m^2)$, $i = 44.0(A)$ | 65 |
| A.9 | .5 in. cylinder with $S=1$ in.; $U = 14.9(m/s)$, $T = 22.8(^{\circ}C)$, $q = 1030(W/m^2)$, $i = 44.0(A)$ | 66 |
| A.10 | .5 in. cylinder with $S=1$ in.; $U = 12.6(m/s)$, $T = 22.5(^{\circ}C)$, $q = 849(W/m^2)$, $i = 40.0(A)$ | 66 |
| A.11 | .5 in. cylinder with $S=1$ in.; $U = 10.0(m/s)$, $T = 22.5(^{\circ}C)$, $q = 769(W/m^2)$, $i = 38.0(A)$ | 67 |
| A.12 | .5 in. cylinder with $S=1$ in.; $U = 8.7(m/s)$, $T = 22.2(^{\circ}C)$, $q = 703(W/m^2)$, $i = 36.0(A)$ | 67 |
| A.13 | .5 in. cylinder with $S=1$ in.; $U = 7.5(m/s)$, $T = 22.4(^{\circ}C)$, $q = 615(W/m^2)$, $i = 34.0(A)$ | 68 |
| A.14 | .5 in. cylinder with $S=1$ in.; $U = 7.5(m/s)$, $T = 22.0(^{\circ}C)$, $q = 615(W/m^2)$, $i = 34.0(A)$ | 68 |
| A.15 | .5 in. cylinder with $S=1$ in.; $U = 6.0(m/s)$, $T = 22.0(^{\circ}C)$, $q = 546(W/m^2)$, $i = 32.0(A)$ | 69 |

| | | |
|------|--|----|
| A.16 | .5 in. cylinder with $S=1$ in.; $U = 5.0(m/s)$, $T = 22.1(^{\circ}C)$, $q = 479(W/m^2)$, $i = 30.0(A)$ | 69 |
| | A.a-ii: Data and Results for 0.5" Cylinder at Different Velocities; $D = 4"$ | 70 |
| A.17 | .5 in. cylinder with $D=4$ in.; $U = 30.0(m/s)$, $T = 21.7(^{\circ}C)$, $q = 1785(W/m^2)$, $i = 58.0(A)$ | 71 |
| A.18 | .5 in. cylinder with $D=4$ in.; $U = 30.0(m/s)$, $T = 21.6(^{\circ}C)$, $q = 1810(W/m^2)$, $i = 58.0(A)$ | 71 |
| A.19 | .5 in. cylinder with $D=4$ in.; $U = 27.4(m/s)$, $T = 21.4(^{\circ}C)$, $q = 1584(W/m^2)$, $i = 54.7(A)$ | 72 |
| A.20 | .5 in. cylinder with $D=4$ in.; $U = 24.9(m/s)$, $T = 21.5(^{\circ}C)$, $q = 1436(W/m^2)$, $i = 52.0(A)$ | 72 |
| A.21 | .5 in. cylinder with $D=4$ in.; $U = 22.6(m/s)$, $T = 21.4(^{\circ}C)$, $q = 1423(W/m^2)$, $i = 52.0(A)$ | 73 |
| A.22 | .5 in. cylinder with $D=4$ in.; $U = 20.0(m/s)$, $T = 21.3(^{\circ}C)$, $q = 1332(W/m^2)$, $i = 50.0(A)$ | 73 |
| A.23 | .5 in. cylinder with $D=4$ in.; $U = 17.6(m/s)$, $T = 21.2(^{\circ}C)$, $q = 1259(W/m^2)$, $i = 48.7(A)$ | 74 |
| A.24 | .5 in. cylinder with $D=4$ in.; $U = 14.8(m/s)$, $T = 21.0(^{\circ}C)$, $q = 1028(W/m^2)$, $i = 44.0(A)$ | 74 |
| A.25 | .5 in. cylinder with $D=4$ in.; $U = 15.0(m/s)$, $T = 21.3(^{\circ}C)$, $q = 1028(W/m^2)$, $i = 44.0(A)$ | 75 |
| A.26 | .5 in. cylinder with $D=4$ in.; $U = 12.7(m/s)$, $T = 20.8(^{\circ}C)$, $q = 938(W/m^2)$, $i = 42.0(A)$ | 75 |

| | | |
|------|---|----|
| A.27 | .5 in. cylinder with $D=4$ in.; $U = 9.9(m/s)$, $T = 20.8(^{\circ}C)$, $q = 778(W/m^2)$, $i = 38.3(A)$ | 76 |
| A.28 | .5 in. cylinder with $D=4$ in.; $U = 8.7(m/s)$, $T = 20.7(^{\circ}C)$, $q = 716(W/m^2)$, $i = 36.7(A)$ | 76 |
| A.29 | .5 in. cylinder with $D=4$ in.; $U = 7.4(m/s)$, $T = 20.8(^{\circ}C)$, $q = 621(W/m^2)$, $i = 34.3(A)$ | 77 |
| A.30 | .5 in. cylinder with $D=4$ in.; $U = 7.5(m/s)$, $T = 20.7(^{\circ}C)$, $q = 631(W/m^2)$, $i = 34.4(A)$ | 77 |
| A.31 | .5 in. cylinder with $D=4$ in.; $U = 6.0(m/s)$, $T = 20.5(^{\circ}C)$, $q = 544(W/m^2)$, $i = 32.0(A)$ | 78 |
| A.32 | .5 in. cylinder with $D=4$ in.; $U = 5.0(m/s)$, $T = 20.5(^{\circ}C)$, $q = 490(W/m^2)$, $i = 30.4(A)$ | 78 |
| | A.a-iii: Data and Results for 1" Cylinder at Different Velocities; $S = 0.5"$ | 79 |
| A.33 | 1 in. cylinder with $S=.5$ in.; $U = 30.0(m/s)$, $T = 24.4(^{\circ}C)$, $q = 1559(W/m^2)$, $i = 170.0(A)$ | 80 |
| A.34 | 1 in. cylinder with $S=.5$ in.; $U = 29.9(m/s)$, $T = 24.5(^{\circ}C)$, $q = 1555(W/m^2)$, $i = 170.0(A)$ | 81 |
| A.35 | 1 in. cylinder with $S=.5$ in.; $U = 27.6(m/s)$, $T = 24.2(^{\circ}C)$, $q = 1438(W/m^2)$, $i = 163.0(A)$ | 82 |
| A.36 | 1 in. cylinder with $S=.5$ in.; $U = 24.8(m/s)$, $T = 24.2(^{\circ}C)$, $q = 1381(W/m^2)$, $i = 160.0(A)$ | 83 |
| A.37 | 1 in. cylinder with $S=.5$ in.; $U = 22.4(m/s)$, $T = 24.0(^{\circ}C)$, $q = 1212(W/m^2)$, $i = 150.0(A)$ | 84 |

| | | |
|------|---|-----------|
| A.38 | 1 in. cylinder with $S=.5$ in.; $U = 20.0(m/s)$, $T = 24.2(^{\circ}C)$, $q = 1213(W/m^2)$, $i = 150.0(A)$ | 85 |
| A.39 | 1 in. cylinder with $S=.5$ in.; $U = 17.5(m/s)$, $T = 24.1(^{\circ}C)$, $q = 1095(W/m^2)$, $i = 143.0(A)$ | 86 |
| A.40 | 1 in. cylinder with $S=.5$ in.; $U = 15.0(m/s)$, $T = 23.9(^{\circ}C)$, $q = 1058(W/m^2)$, $i = 140.0(A)$ | 87 |
| A.41 | 1 in. cylinder with $S=.5$ in.; $U = 15.1(m/s)$, $T = 23.8(^{\circ}C)$, $q = 1060(W/m^2)$, $i = 140.0(A)$ | 88 |
| A.42 | 1 in. cylinder with $S=.5$ in.; $U = 12.4(m/s)$, $T = 23.8(^{\circ}C)$, $q = 911(W/m^2)$, $i = 130.0(A)$ | 89 |
| A.43 | 1 in. cylinder with $S=.5$ in.; $U = 10.1(m/s)$, $T = 23.7(^{\circ}C)$, $q = 651(W/m^2)$, $i = 110.0(A)$ | 90 |
| A.44 | 1 in. cylinder with $S=.5$ in.; $U = 8.7(m/s)$, $T = 23.6(^{\circ}C)$, $q = 776(W/m^2)$, $i = 120.0(A)$ | 91 |
| A.45 | 1 in. cylinder with $S=.5$ in.; $U = 7.5(m/s)$, $T = 23.5(^{\circ}C)$, $q = 801(W/m^2)$, $i = 120.0(A)$ | 92 |
| A.46 | 1 in. cylinder with $S=.5$ in.; $U = 7.5(m/s)$, $T = 23.2(^{\circ}C)$, $q = 539(W/m^2)$, $i = 100.0(A)$ | 93 |
| A.47 | 1 in. cylinder with $S=.5$ in.; $U = 6.2(m/s)$, $T = 23.3(^{\circ}C)$, $q = 538(W/m^2)$, $i = 100.0(A)$ | 94 |
| A.48 | 1 in. cylinder with $S=.5$ in.; $U = 5.0(m/s)$, $T = 23.2(^{\circ}C)$, $q = 432(W/m^2)$, $i = 90.0(A)$ | 95 |
| | A.a-iv: Data and Results for 1" Cylinder at Different Velocities; $S = 1"$ | 96 |

| | | |
|------|--|-----|
| A.49 | 1 in. cylinder with $S=1$ in.; $U = 30.1(m/s)$, $T = 23.9(^{\circ}C)$, $q = 1743(W/m^2)$, $i = 180.0(A)$ | 97 |
| A.50 | 1 in. cylinder with $S=1$ in.; $U = 30.0(m/s)$, $T = 24.5(^{\circ}C)$, $q = 1757(W/m^2)$, $i = 180.0(A)$ | 98 |
| A.51 | 1 in. cylinder with $S=1$ in.; $U = 27.7(m/s)$, $T = 24.3(^{\circ}C)$, $q = 1389(W/m^2)$, $i = 160.0(A)$ | 99 |
| A.52 | 1 in. cylinder with $S=1$ in.; $U = 25.0(m/s)$, $T = 24.4(^{\circ}C)$, $q = 1395(W/m^2)$, $i = 160.0(A)$ | 100 |
| A.53 | 1 in. cylinder with $S=1$ in.; $U = 22.4(m/s)$, $T = 23.9(^{\circ}C)$, $q = 1207(W/m^2)$, $i = 150.0(A)$ | 101 |
| A.54 | 1 in. cylinder with $S=1$ in.; $U = 19.9(m/s)$, $T = 24.1(^{\circ}C)$, $q = 1219(W/m^2)$, $i = 150.0(A)$ | 102 |
| A.55 | 1 in. cylinder with $S=1$ in.; $U = 17.5(m/s)$, $T = 23.6(^{\circ}C)$, $q = 1051(W/m^2)$, $i = 140.0(A)$ | 103 |
| A.56 | 1 in. cylinder with $S=1$ in.; $U = 15.0(m/s)$, $T = 23.5(^{\circ}C)$, $q = 914(W/m^2)$, $i = 130.0(A)$ | 104 |
| A.57 | 1 in. cylinder with $S=1$ in.; $U = 15.2(m/s)$, $T = 23.8(^{\circ}C)$, $q = 917(W/m^2)$, $i = 130.0(A)$ | 105 |
| A.58 | 1 in. cylinder with $S=1$ in.; $U = 12.6(m/s)$, $T = 23.7(^{\circ}C)$, $q = 771(W/m^2)$, $i = 120.0(A)$ | 106 |
| A.59 | 1 in. cylinder with $S=1$ in.; $U = 10.0(m/s)$, $T = 23.6(^{\circ}C)$, $q = 652(W/m^2)$, $i = 110.0(A)$ | 107 |
| A.60 | 1 in. cylinder with $S=1$ in.; $U = 8.8(m/s)$, $T = 23.7(^{\circ}C)$, $q = 650(W/m^2)$, $i = 110.0(A)$ | 108 |

| | | |
|---|--|------------|
| A.61 | 1 in. cylinder with $S=1$ in.; $U = 7.5(m/s)$, $T = 23.6(^{\circ}C)$, $q = 540(W/m^2)$, $i = 100.0(A)$ | 109 |
| A.62 | 1 in. cylinder with $S=1$ in.; $U = 7.6(m/s)$, $T = 23.3(^{\circ}C)$, $q = 532(W/m^2)$, $i = 100.0(A)$ | 110 |
| A.63 | 1 in. cylinder with $S=1$ in.; $U = 6.0(m/s)$, $T = 23.3(^{\circ}C)$, $q = 429(W/m^2)$, $i = 90.0(A)$ | 111 |
| A.64 | 1 in. cylinder with $S=1$ in.; $U = 5.1(m/s)$, $T = 23.4(^{\circ}C)$, $q = 443(W/m^2)$, $i = 90.0(A)$ | 112 |
| A.a-v: Data and Results for 1" Cylinder at Different Velocities; $S = 1.5"$, $D = 4"$ | | 113 |
| A.65 | 1 in. cylinder with $S=1.5$ in.; $U = 30.2(m/s)$, $T = 24.4(^{\circ}C)$, $q = 1611(W/m^2)$, $i = 173.3(A)$ | 114 |
| A.66 | 1 in. cylinder with $S=1.5$ in.; $U = 30.0(m/s)$, $T = 24.4(^{\circ}C)$, $q = 1559(W/m^2)$, $i = 170.0(A)$ | 115 |
| A.67 | 1 in. cylinder with $S=1.5$ in.; $U = 27.7(m/s)$, $T = 24.5(^{\circ}C)$, $q = 1376(W/m^2)$, $i = 160.0(A)$ | 116 |
| A.68 | 1 in. cylinder with $S=1.5$ in.; $U = 25.1(m/s)$, $T = 24.3(^{\circ}C)$, $q = 1383(W/m^2)$, $i = 160.0(A)$ | 117 |
| A.69 | 1 in. cylinder with $S=1.5$ in.; $U = 22.6(m/s)$, $T = 24.3(^{\circ}C)$, $q = 1206(W/m^2)$, $i = 150.0(A)$ | 118 |
| A.70 | 1 in. cylinder with $S=1.5$ in.; $U = 20.0(m/s)$, $T = 24.2(^{\circ}C)$, $q = 1209(W/m^2)$, $i = 150.0(A)$ | 119 |
| A.71 | 1 in. cylinder with $S=1.5$ in.; $U = 17.7(m/s)$, $T = 24.1(^{\circ}C)$, $q = 1054(W/m^2)$, $i = 140.0(A)$ | 120 |

| | | |
|--|---|-----|
| A.72 | 1 in. cylinder with $S=1.5$ in.; $U = 15.0(m/s)$, $T = 23.6(^{\circ}C)$, $q = 912(W/m^2)$, $i = 130.0(A)$ | 121 |
| A.73 | 1 in. cylinder with $S=1.5$ in.; $U = 15.1(m/s)$, $T = 24.0(^{\circ}C)$, $q = 913(W/m^2)$, $i = 130.0(A)$ | 122 |
| A.74 | 1 in. cylinder with $S=1.5$ in.; $U = 12.4(m/s)$, $T = 23.6(^{\circ}C)$, $q = 770(W/m^2)$, $i = 120.0(A)$ | 123 |
| A.75 | 1 in. cylinder with $S=1.5$ in.; $U = 9.9(m/s)$, $T = 23.7(^{\circ}C)$, $q = 651(W/m^2)$, $i = 110.0(A)$ | 124 |
| A.76 | 1 in. cylinder with $S=1.5$ in.; $U = 8.6(m/s)$, $T = 23.7(^{\circ}C)$, $q = 641(W/m^2)$, $i = 110.0(A)$ | 125 |
| A.77 | 1 in. cylinder with $S=1.5$ in.; $U = 7.5(m/s)$, $T = 23.8(^{\circ}C)$, $q = 544(W/m^2)$, $i = 100.0(A)$ | 126 |
| A.78 | 1 in. cylinder with $S=1.5$ in.; $U = 7.5(m/s)$, $T = 23.5(^{\circ}C)$, $q = 530(W/m^2)$, $i = 100.0(A)$ | 127 |
| A.79 | 1 in. cylinder with $S=1.5$ in.; $U = 5.8(m/s)$, $T = 23.4(^{\circ}C)$, $q = 432(W/m^2)$, $i = 90.0(A)$ | 128 |
| A.80 | 1 in. cylinder with $S=1.5$ in.; $U = 5.0(m/s)$, $T = 23.5(^{\circ}C)$, $q = 435(W/m^2)$, $i = 90.0(A)$ | 129 |
| A.a-vi: Data and Results for 1" Cylinder at Different Velocities; $S = 2"$ | | 130 |
| A.81 | 1 in. cylinder with $S=2$ in.; $U = 29.8(m/s)$, $T = 22.8(^{\circ}C)$, $q = 1549(W/m^2)$, $i = 170.0(A)$ | 131 |
| A.82 | 1 in. cylinder with $S=2$ in.; $U = 30.1(m/s)$, $T = 22.6(^{\circ}C)$, $q = 1742(W/m^2)$, $i = 180.0(A)$ | 132 |

| | | |
|------|--|-----|
| A.83 | 1 in. cylinder with $S=2$ in.; $U = 27.3(m/s)$, $T = 22.3(^{\circ}C)$, $q = 1550(W/m^2)$, $i = 170.0(A)$ | 133 |
| A.84 | 1 in. cylinder with $S=2$ in.; $U = 25.0(m/s)$, $T = 22.4(^{\circ}C)$, $q = 1376(W/m^2)$, $i = 160.0(A)$ | 134 |
| A.85 | 1 in. cylinder with $S=2$ in.; $U = 22.6(m/s)$, $T = 22.4(^{\circ}C)$, $q = 1373(W/m^2)$, $i = 160.0(A)$ | 135 |
| A.86 | 1 in. cylinder with $S=2$ in.; $U = 19.9(m/s)$, $T = 22.0(^{\circ}C)$, $q = 1209(W/m^2)$, $i = 150.0(A)$ | 136 |
| A.87 | 1 in. cylinder with $S=2$ in.; $U = 17.5(m/s)$, $T = 22.1(^{\circ}C)$, $q = 1051(W/m^2)$, $i = 140.0(A)$ | 137 |
| A.88 | 1 in. cylinder with $S=2$ in.; $U = 15.0(m/s)$, $T = 21.8(^{\circ}C)$, $q = 898(W/m^2)$, $i = 130.0(A)$ | 138 |
| A.89 | 1 in. cylinder with $S=2$ in.; $U = 14.8(m/s)$, $T = 21.8(^{\circ}C)$, $q = 1052(W/m^2)$, $i = 140.0(A)$ | 139 |
| A.90 | 1 in. cylinder with $S=2$ in.; $U = 12.5(m/s)$, $T = 21.6(^{\circ}C)$, $q = 913(W/m^2)$, $i = 130.0(A)$ | 140 |
| A.91 | 1 in. cylinder with $S=2$ in.; $U = 10.0(m/s)$, $T = 21.6(^{\circ}C)$, $q = 773(W/m^2)$, $i = 120.0(A)$ | 141 |
| A.92 | 1 in. cylinder with $S=2$ in.; $U = 8.7(m/s)$, $T = 21.5(^{\circ}C)$, $q = 654(W/m^2)$, $i = 110.0(A)$ | 142 |
| A.93 | 1 in. cylinder with $S=2$ in.; $U = 7.5(m/s)$, $T = 21.6(^{\circ}C)$, $q = 537(W/m^2)$, $i = 100.0(A)$ | 143 |
| A.94 | 1 in. cylinder with $S=2$ in.; $U = 7.4(m/s)$, $T = 21.5(^{\circ}C)$, $q = 645(W/m^2)$, $i = 110.0(A)$ | 144 |

| | | |
|---|--|-----|
| A.95 | 1 in. cylinder with $S=2$ in.; $U = 6.0(m/s)$, $T = 21.4(^{\circ}C)$, $q = 535(W/m^2)$, $i = 100.0(A)$ | 145 |
| A.96 | 1 in. cylinder with $S=2$ in.; $U = 5.0(m/s)$, $T = 21.4(^{\circ}C)$, $q = 436(W/m^2)$, $i = 90.0(A)$ | 146 |
| A.a-vii: Data and Results for 2" Cylinder at Different Velocities; $S = 1"$, $D = 4"$ | | 147 |
| A.97 | 2 in. cylinder with $S=1$ in.; $U = 29.7(m/s)$, $T = 22.8(^{\circ}C)$, $q = 1090(W/m^2)$, $i = 333.3(A)$ | 148 |
| A.98 | 2 in. cylinder with $S=1$ in.; $U = 30.0(m/s)$, $T = 22.8(^{\circ}C)$, $q = 1082(W/m^2)$, $i = 333.3(A)$ | 149 |
| A.99 | 2 in. cylinder with $S=1$ in.; $U = 27.5(m/s)$, $T = 22.8(^{\circ}C)$, $q = 1085(W/m^2)$, $i = 333.3(A)$ | 150 |
| A.100 | 2 in. cylinder with $S=1$ in.; $U = 25.0(m/s)$, $T = 22.8(^{\circ}C)$, $q = 1092(W/m^2)$, $i = 333.3(A)$ | 151 |
| A.101 | 2 in. cylinder with $S=1$ in.; $U = 22.4(m/s)$, $T = 22.4(^{\circ}C)$, $q = 1089(W/m^2)$, $i = 333.3(A)$ | 152 |
| A.102 | 2 in. cylinder with $S=1$ in.; $U = 20.2(m/s)$, $T = 22.4(^{\circ}C)$, $q = 1094(W/m^2)$, $i = 333.3(A)$ | 153 |
| A.103 | 2 in. cylinder with $S=1$ in.; $U = 17.4(m/s)$, $T = 21.8(^{\circ}C)$, $q = 1073(W/m^2)$, $i = 330.0(A)$ | 154 |
| A.104 | 2 in. cylinder with $S=1$ in.; $U = 15.3(m/s)$, $T = 22.7(^{\circ}C)$, $q = 882(W/m^2)$, $i = 300.0(A)$ | 155 |
| A.105 | 2 in. cylinder with $S=1$ in.; $U = 15.0(m/s)$, $T = 22.0(^{\circ}C)$, $q = 940(W/m^2)$, $i = 310.0(A)$ | 156 |

| | | |
|-------|---|-----|
| A.106 | 2 in. cylinder with $S=1$ in.; $U = 12.4(m/s)$, $T = 24.2(^{\circ}C)$, $q = 825(W/m^2)$, $i = 290.0(A)$ | 157 |
| A.107 | 2 in. cylinder with $S=1$ in.; $U = 9.9(m/s)$, $T = 24.5(^{\circ}C)$, $q = 720(W/m^2)$, $i = 270.0(A)$ | 158 |
| A.108 | 2 in. cylinder with $S=1$ in.; $U = 8.7(m/s)$, $T = 23.4(^{\circ}C)$, $q = 612(W/m^2)$, $i = 250.0(A)$ | 159 |
| A.109 | 2 in. cylinder with $S=1$ in.; $U = 7.5(m/s)$, $T = 24.2(^{\circ}C)$, $q = 564(W/m^2)$, $i = 240.0(A)$ | 160 |
| A.110 | 2 in. cylinder with $S=1$ in.; $U = 7.4(m/s)$, $T = 23.7(^{\circ}C)$, $q = 532(W/m^2)$, $i = 233.3(A)$ | 161 |
| A.111 | 2 in. cylinder with $S=1$ in.; $U = 6.1(m/s)$, $T = 24.0(^{\circ}C)$, $q = 387(W/m^2)$, $i = 200.0(A)$ | 162 |
| A.112 | 2 in. cylinder with $S=1$ in.; $U = 5.0(m/s)$, $T = 24.3(^{\circ}C)$, $q = 393(W/m^2)$, $i = 200.0(A)$ | 163 |
| | A.b: Data and Results at X_{max}, in Different Velocities, and for each of the 7 Cases | 164 |
| A.113 | .5in. cylinder with 1in. step height: Results for the points of maximum heat transfer rate | 165 |
| A.114 | .5in. cylinder with 4in. step diameter: Results for the points of maximum heat transfer rate | 166 |
| A.115 | 1in. cylinder with 2in. step diameter: Results for the points of maximum heat transfer rate | 167 |
| A.116 | 1in. cylinder with 1in. step height: Results for the points of maximum heat transfer rate | 168 |

| | |
|--|-----|
| A.117 1in. cylinder with 4in. step diameter: Results for the points of maximum heat transfer rate | 169 |
| A.118 1in. cylinder with 5in. step diameter: Results for the points of maximum heat transfer rate | 170 |
| A.119 2in. cylinder: Results for the points of maximum heat trans- fer rate | 171 |
| A.c: X_r , X_{max} , $cond_{max}\%$ for 7 cases, at $U = 7.5, 15,$ and 30 m/s | 172 |
| A.120 $d = .5''$, $D = 2.5''$, $S = 1''$ | 173 |
| A.121 $d = .5''$, $D = 4''$, $S = 1.75''$ | 173 |
| A.122 $d = 1''$, $D = 2''$, $S = 0.5''$ | 173 |
| A.123 $d = 1''$, $D = 3''$, $S = 1''$ | 173 |
| A.124 $d = 1''$, $D = 4''$, $S = 1.5''$ | 173 |
| A.125 $d = 1''$, $D = 5''$, $S = 2''$ | 174 |
| A.126 $d = 2''$, $D = 4''$, $S = 1''$ | 174 |

List of Figures

| | | |
|-----|---|-----|
| 1.1 | Schematic of the Flow Configuration in the present study . . . | 3 |
| 2.1 | Assembly details of the cylinder, step, and power terminal bar | 18 |
| 2.2 | Schematic of the test assembly inside the wind tunnel | 24 |
| 2.3 | Schematic of the experimental set up and instrumentation . . . | 25 |
| 2.4 | Top and sectional views of the test cylinder showing the in- stallation of thermocouple wires | 25 |
| 4.1 | Scheme of the one dimensional non-equally spaced grid points | 33 |
| 5.1 | Flow separation and boundary layers in different cylinder- step geometries | 41 |
| 5.2 | Dependence of the reattachment length on the state of the separation boundary layer (Eaton and Johnston, 1981) . . . | 48 |
| B.1 | Effect of transverse convex curvature on heat transfer for the fixed $D = 4''$ | 176 |
| B.2 | Effect of transverse convex curvature on heat transfer for the fixed $S = 1''$ | 177 |

| | | |
|-----|--|-----|
| B.3 | Effect of step change on heat transfer for the fixed $d = 1''$. . . | 178 |
| B.4 | Effect of aspect ratio(D/d) on maximum heat transfer | 179 |
| B.5 | Scattergram of $Nu_{S,max}$ in three geometrical categories . . . | 180 |
| B.6 | Overall Scattergram of $Nu_{S,max}$ and its correlation with (d/D) and Re_S | 181 |
| B.7 | Comparison of the normalized results for 4'' step diameter in three cylinders, each in seven velocity cases | 182 |
| B.8 | Flow visualization: Sample of an ink-dot streakline pattern recorded on transparent film | 183 |

Nomenclature

Symbols Description

| | |
|-------------|--|
| <i>b</i> | Thickness of the wall of cylinder [m] |
| <i>C</i> | Specific heat [$\frac{kJ}{kg \cdot ^\circ C}$] |
| <i>cond</i> | Axial conduction [W/m^2] |
| <i>d</i> | Diameter of the cylinder [m] |
| <i>D</i> | Diameter of the step [m] |
| <i>f</i> | Regression factor |
| <i>h</i> | Coefficient of the convective heat transfer [$W/(m^2 \cdot ^\circ C)$] |
| <i>i</i> | Electric current [Ampere] |
| <i>I</i> | Index of uncertainty |
| <i>k</i> | Thermal conductivity [$W/(m \cdot ^\circ C)$] |
| <i>L</i> | Length of the thermocouple line on the cylinder [mm] |
| <i>n</i> | Frequency of the vortice shedding [Hz] |
| <i>N</i> | Number of measurements |
| <i>Nu</i> | Nusselt number [mostly $\frac{h \cdot S}{k_f}$] |
| <i>do</i> | Outside diameter of the cylinder [mm] |
| <i>di</i> | Inside diameter of the cylinder [mm] |

| | |
|------|--|
| Pr | Prandtl number [$\frac{C_p \mu}{k_f}$, or ν/α] |
| q | Surface heat flux [W/m^2] |
| r | Cylindrical axis of coordinates |
| Re | Reynolds number [mostly $\frac{U_s}{\nu}$] |
| s | Standard deviation of samples |
| S | Height of backward step [m] |
| St | Stanton number [$\frac{h}{\rho C_p U}$, or $\frac{Nu}{Re Pr}$] |
| t | Wall temperature of cylinder [$^{\circ}C$] |
| T | Upstream temperature [$^{\circ}C$] |
| U | Upstream velocity [m/sec] |
| v | Voltage between the first and last probes on the cylinder [$Volt$] |
| w | Uncertainty |
| x | Axis of coordinates |
| X | Axial position along the cylinder [m] |

Greek letters

| | |
|------------|--|
| α | Coefficient of temperature resistivity [$/^{\circ}C$] |
| ϵ | Emissivity |
| μ | Dynamic(absolute) viscosity [$(N.S)/m^2$] |
| ν | Kinematic viscosity [m^2/S] |
| ρ | Density [kg/m^3] |
| σ | Stefan Boltzmann constant [$5.669 \times 10^{-8} W/m^2.K^4$] |

Subscripts

| | |
|------------|--|
| <i>d</i> | With respect to the diameter of the cylinder |
| <i>f</i> | Flow properties at film temperature condition |
| <i>o</i> | Diameter of upstream orifice |
| <i>O</i> | Diameter of downstream channel or pipe |
| <i>max</i> | Point of maximum heat transfer |
| <i>P</i> | Evaluated at constant pressure |
| <i>r</i> | Reattachment point, with respect to the radius |
| <i>s</i> | Solid properties |
| <i>S</i> | Step height |
| <i>x</i> | With respect to x (local) |

Superscripts

| | |
|------------|------------|
| . | Time rate |
| — | Average |
| <i>atm</i> | Atmosphere |

Chapter 1

Introduction

In many flows of practical interest, the study of the unavoidable phenomena of separation, reattachment, and redevelopment of the boundary layer arising from backward-facing step geometries and the point of maximum heat transfer demands research and investigation. The phenomena mentioned can cause substantial variation in local heat transfer coefficients.

Such flows are extensively found in the design of nuclear reactors, combustion chambers of jet engines, re-entry space vehicles, micro-electronic boards, and so on.

Transverse curvature effects on boundary layer development are of importance in many situations encountered in engineering, especially in the heat exchanger industry.

1.1 Some Theoretical Aspects of Fluid Dynamics

1.1.1 Turbulent Boundary Layer along Circular Cylinders

Appropriate to the present study, the following common features may be summarized from the results of the experimental and analytical studies carried out for the axial turbulent flow on convex curvatures by Lee and Kim (1993), Kim et al. (1990), Sparrow et al. (1963), Yu (1958), and Eckert (1952). The review is given for the cases when the ratio of the thickness of the developed boundary layer to the radius of curvature becomes as large as unity.

The flow field on a circular cylinder may be divided into two regions. The region adjacent to the wall is purely laminar, while the region away from the wall, i.e., the core, is purely turbulent. The thickness of the boundary layer increases with axial distance, steeply at first and then more smoothly downstream. Therefore, the larger the local Reynolds number (Re_z), the thicker is the boundary layer. Substituting the radius of cylinder by the radius Reynolds number (Re_r), it could be said that the smaller the Re_r , the greater is the curvature effect. In addition, for the flow along a cylinder, an asymptotic nature of the boundary layer characteristics has been noticed. It means that for a given Re_r , as the ratio of the boundary layer thickness to the radius of cylinder ($\frac{\delta}{r}$) decreases, any characteristic curve for the cylinder approaches asymptotically to that of a flat plate. Since one of the reviewed papers dealt with compressible flow (Eckert, 1952), it is to mention that flow

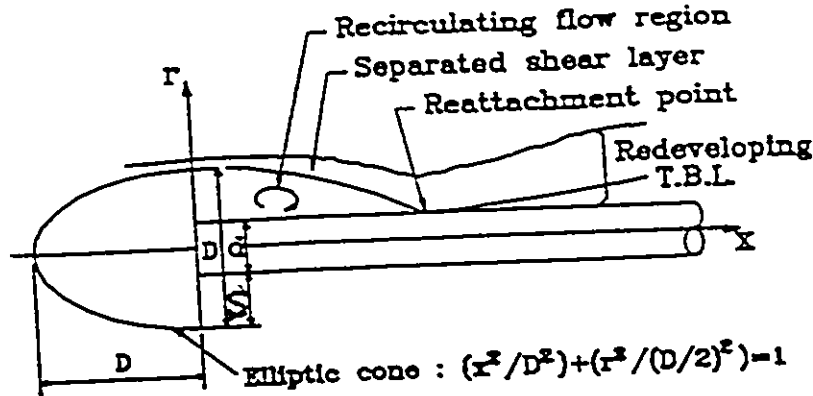


Figure 1.1: Schematic of the Flow Configuration in the present study

compressibility enhances the effect of curvature in general except for the displacement thickness where a slight decrease was found.

It has been seen that the boundary layer thickness and the displacement thickness on a cylinder are less than that on a flat plate, while the momentum thickness and the local and mean friction coefficients are higher.

1.1.2 Flow Species and Model Geometries in Backward-Facing Step Flow Separation

The phenomenon of separation in backward-facing step flow happens when a steady fluid flow, attached to a solid surface, breaks away and produces a region of separated flow close to the surface. The event may take place on a smooth surface and starts upon the point of an abrupt change in geometry of the flow, i.e. at the blunt base. The separated boundary layer encompasses a region called a “recirculation region” or “separation bubble”. The bubble stretches from the edge of the step up to the point where it reattaches on the solid surface. This point is known as the “reattachment point”. The recircu-

lation region is mainly covered by reverse flow, in which the velocity reaches up to about 40% of that in free stream (Suzuki et al., 1991). Thereafter the redevelopment of the boundary layer begins at the reattachment point, and attains a thickness of the order of magnitude of the radius of cylinder. The flow regions mentioned can be seen from Figure 1.1 .

In a general sense, the flow could be classified as either *internal* or *external flow*, yet from the aspect of dimensionality, the flow is studied either as a two-dimensional or as an axisymmetric flow.

Moreover, from the view point of the boundary layer theory, a backward-facing step flow is classified (Smith and Wood, 1985) among those for which the boundary layer responds to an extremely severe perturbation. It is usually accompanied by a change in the flow species. Since in such a case the boundary layer does not exhibit self-preservation, a boundary layer approach to solution is impossible (ibid). The main cause of flow separation is known to be the adverse pressure gradient in a viscous flow.

1.1.3 Physics of Heat Transfer in a Turbulent Boundary Layer

The physical process of heat transfer in a separated flow could be partially explained (Chang, 1970) by the following heat transfer mechanisms, namely:

1. Conduction between wall and fluid in the separated region
2. Conduction through the shear layer

3. convection by exchange of fluid between the separated region and external flow

1.2 Background Study

The major studies on turbulent separation have been carried out by aircraft aerodynamicists who applied boundary layer theory either to external flow over airfoils or to internal flow through diffusers.

For the present study, a review, insofar as possible, of the studies on heat transfer affected by convex curvature or backward-facing step will be presented.

1.2.1 Effect of Transverse Convex Curvature on Heat Transfer

The effect of transverse convex curvature on convective heat transfer has been identified, experimentally and analytically, by Lee, Kim, and Ma (Lee and Kim, 1993; Kim et al., 1990), at a time when no explicit study of the transverse curvature (TVC) effect on heat transfer had been done (ibid). The experimental study was presented for a constant pressure, incompressible flow along the heated test cylinders. The diameters of cylinders (2", 1", and 0.5") were chosen so that the thickness of the developed boundary layer remained in the order of magnitude of the cylinder radius. To avoid separation, the leading edge of the cylinders was streamlined with a conical nose made of a plastic material, Derlin (Compare between "b" and "c" in

Figure 5.1). The analytical study was followed, based on a mixing length model, for the similar case.

They found that whereas transverse *concave* curvature of the surface has little effect on the radial development of flow turbulence, the effect of transverse *convex* curvature is significant.

However, the mentioned study (*ibid*) proposes that the transverse convex curvature effect on heat transfer is significant as long as the thickness of the boundary layer, in a viscous flow, stays in the order of magnitude of the radius of the curvature.

In studying the effect of Transverse Convex Curvature on heat transfer, it has been observed that the magnitude of the Stanton number decreases with increasing values of the cylinder radius, and is always greater than that for flow over a flat plate.

In their experimental work, the above mentioned researchers (Kim et al., 1990) have taken into account the axial wall conduction heat transfer and radiation as errors in the final values of heat transfer coefficients. They have calculated, by using an energy balance equation, a maximum of 13% axial wall conduction at the supposed reattachment point, $X \approx 3 \text{ cm}$, and a maximum of 0.4% radiation heat loss to the walls of the wind tunnel. The energy balance equation will be discussed further in Section 4.2, "Axial Conduction Heat Transfer".

1.2.2 Effect of a Backward-Facing Step

The results from the limited number of the related articles, which will be discussed further, show similar general features for a variety of geometries, in both external and internal flows.

The heat transfer coefficient undergoes a drop within a short length distance right after separation, followed by a rise leading to a sharp maximum at the reattachment zone.

However, the point of maximum heat transfer (X_{max}) does not necessarily coincide with the reattachment point, X_r , a fact which has been mistaken by early researchers. The point is discussed in Section 1.2.3, "Distinction Between ...". In addition, the axial location of the reattachment point with respect to the blunt base is of the order of magnitude of the cylinder/duct diameter. Further, the formation and full redevelopment of the boundary layer requires a much longer axial distance.

However, due to some numerical difference between the results of researches on the two categories of external and internal flows, the review is pursued separately for each.

External Flow

There seems to be hardly any study done about the effect of a step change on the external axisymmetric type of backward-facing step flow, as far as the author is aware. Apart from a study done by Suzuki et al. (1991) in seeking for the possibility of heat transfer enhancement in the recirculation region of a backward-facing step, through insertion of another obstruction

—a cylinder— near the top corner of the step, the rest, as it is reviewed and referenced in the present study, have concentrated on studying different theoretical aspects of heat transfer and turbulent flow in the reattachment zone of both external and internal flows.

Ota and Kon (1977, 1975, 1974) have conducted experiments on air flow over a blunt-edge flat plate (two dimensional) and a longitudinal blunt-face circular cylinder (Figure 5.1, C). The leading edge of a blunt-face stepless cylinder which causes flow separation may be considered as a special case of a step that has $D = d$ and $S = 0$. They correlated the maximum heat transfer coefficient and the Reynolds number by the method of least squares, to obtain:

$$Nu_{d,max} = 0.0804 Re_d^{0.747} \quad (1.1)$$

which happens at about $x/d = 1.4$ from the leading edge of the blunt cylinder. Similarly, in the case of the flat plate:

$$Nu_{max} = 0.0782 Re^{0.709} \quad (1.2)$$

where both Re and Nu are based on half of the flat plate thickness.

Moreover, they assumed the coincidence of the reattachment point and the point of maximum heat transfer in both cases, and the independence of their locus from the Reynolds number.

In numerical modeling of the Navier-Stokes equations with the $k - \epsilon$ turbulence model for air flow on a blunt circular cylinder ($S = d$), Vaitekunas et al. (1991) have demonstrated the dependency of the separation bubble's length on the level as well on the scale of turbulence of the free stream. For the range $10^3 < Re < 10^5$, they found that the length of the separation

bubble reaches an asymptotic value of about $1.5 d$ when the intensity of free stream turbulence is less than 1%.

A study of two dimensional backward-facing step flow by Tsou et al. (1991) shows that the reattachment point lies at $X_r = 7.6 S$, which is higher than the value of $X_r = 6.6 S$ obtained by Vogel and Eaton (1985) and moreover, through considering the difference existing between the result of their experiment and those of others, they reasoned, by referring to other sources, that the reattachment length increases with an increase in Reynolds number (Re_S).

Internal Flow

The review here is more aimed to highlight the difference between the results of the studies conducted on internal and external flows with backward-facing steps.

An early study, on water flow, with Reynolds and Prandtl numbers ranging respectively from 10,000 to 130,000 and from 3 to 6, was done by Krall and Sparrow (1966), to determine the effect of flow separation on the heat transfer characteristics of a turbulent pipe flow. The degree of separation was varied by employing orifices of various bore diameters. The point of maximum heat transfer coefficient was found to occur at an axial distance of 1.25 to 2.50 pipe diameters from the onset of separation. The study presents an equation of correlation for the peak Nusselt number with respect to the orifice Reynolds number as:

$$Nu_{x,max} = .398 Re_o^{2/3} \quad (1.3)$$

The experimental work by Zemanick and Dougal (1970), with air flow in the region beyond an abrupt expansion in a circular channel with varying upstream-to-downstream diameter ratio, presents a correlation equation as:

$$Nu_{O,max} = .20 Re_o^{2/3} \quad (1.4)$$

The result was later confirmed by Baughn et al. (1984).

1.2.3 Distinction Between the Points of Reattachment and Maximum Heat Transfer

A detailed study of the mechanism of reattaching and redeveloping flow is required for the augmentation of heat transfer in a turbulent backward-step flow.

Until the 1970's, it was assumed (e.g. Ota and Kon, 1970) that the point of maximum heat transfer coefficient (X_{max}) corresponded to the mean reattachment point (X_r); however, by the 1980's, the thermal tuft and zero skin friction extrapolation —through measurements done by the pulsed wall probe— were being used (e.g. Vogel and Eaton, 1985) to visualize the distinction between them. Since the unsteady behavior of the point of reattachment (the point of zero skin friction) does not allow the direct measurement, an extrapolation through the values of skin friction measured within the separation boundary layer is used. The thermal tuft determines the instantaneous flow direction in a thin layer (0.0 to 0.4mm above the wall) of air near the wall, and the function of the pulsed wall probe is to measure the instantaneous velocity very near the wall (less than 0.5mm) of an unsteady, reversing

flow using a heat tracer technique. Both devices (commercially available for use on a flat surface) are adaptations of the hot wire anemometer designed to function in a recirculating flow region (Eaton et al., 1982).

Finally, Sparrow et al. (1987) were those who have distinguished the aforementioned points, X_{max} and X_r , from each other, and have shown by both experimental and numerical methods their interrelation in different flow geometries. They found that the location of flow reattachment (X_r), depending on whether or not the separation bubble is long or short, occurs respectively after or before the location of maximum Nusselt number.

Furthermore, Eaton and Johnston (1981), in an intensive literature review on reattachment, have examined the results of nineteen experimental works, done in subsonic backward-facing step flow. They found that the reattachment length (X_r) under different conditions varies from 4.9 to 8.2 times the step height. They listed *five major influential parameters* on the reattachment length:

1. The effect of changing the state (laminar/turbulent) of the separating boundary layer has been systematically studied. The results are shown in Figure 5.2.
2. A systematic study is needed to determine the extent of the effect of the initial boundary layer thickness on the reattachment length.
3. An examination of a few data available suggests that high levels of the free stream turbulence decrease the reattachment length. Although the magnitude of the effect of the freestream turbulence is likely dependent on i) the initial conditions of the free shear layer and ii) the spectrum

of the freestream turbulence, further investigation into the effect of the freestream turbulence on free-shear layers definitely is needed.

4. The streamwise pressure gradient is in part controlled by the overall system geometry. Its changing effect on the reattachment zone has not been studied systematically, but a trend of increasing reattachment length with increasing expansion ratio is apparent.
5. The aspect ratio of the flow apparatus can also have an effect on the reattachment length. For internal flow it was found that the effect is negligible for aspect ratios greater than ten. For the aspect ratios less than ten, the reattachment length increases if the boundary layer at separation is laminar and decreases if it is turbulent.

These are different from the effect of changing the apex angle of the step (vertex angle of the nose piece) on the down-stream flow when the step diameter at the separation edge is fixed. This effect has been discussed by Ota and Kon (1979). They found that the maximum heat transfer rate is independent of the nose shape, while the reattachment length increases with the wedge angle.

1.2.4 A Conclusion to the Background Study

The phenomena of turbulent separation, reattachment, and redevelopment are not yet well understood, as inferred from the reviewed papers.

The review shows that the quantitative description of the convective heat transfer in separated regions of the backward-facing step flows is still a cum-

bersome task which relies heavily on empirical data. The empirical equations suggested by different authors for predicting heat transfer at the point of reattachment are found to be at variance with each other in either internal or external flow. Moreover, in their equations none of the mentioned researchers considered the parameter of the diameter ratio, i.e. the diameter of the step or orifice to that of the cylinder or channel. In the present study, the parameter of diameter ratio (D/d) implicitly introduces the effect of convex curvature.

For internal flow only, the review shows that the axial length of the point of maximum heat transfer is proportional to the ratio of downstream to upstream diameters, i.e. $X_{max} \propto \frac{D}{d}$. On the other hand, the location of maximum heat transfer moves downstream as the ratio of downstream to upstream diameter increases. In internal flow, this is accompanied with a reduction of step size and pressure gradient. However, no study was found to study the similar effect for the external flow, while for the case of the present study, due to the lack of a pressure gradient, the effect is not so significant.

No effort has been made to study the effect of the geometry of the solid wall on which the flow reattaches, e.g., the effect of change in concave (internal flow) or convex (external flow) curvature on heat transfer.

There is a low heat transfer rate in the recirculation region followed by a steep rise to a maximum near the reattachment point.

1.3 Objective

The purpose of the present study is to investigate experimentally the heat transfer characteristics of turbulent flows along uniformly heated cylindrical tubes of varying diameters with different steps installed on the leading face (see Figure 1.1).

It is intended to study the effect of convex curvature on heat transfer rate, by changing the diameters of cylinder and step. The objective is to determine a correlation among the three parameters of the maximum heat transfer rate, the varying diameters of both cylinder and step, and the Reynolds number.

The present study will calculate and examine the axial conduction rate along the wall of cylinder.

It is also aimed, by means of a flow visualization technique, to verify the distinction between the location of maximum heat transfer and that of the reattachment point.

Chapter 2

Experimental Apparatus and Instruments

The facilities for the present study have previously been used by Kim et al. (1990), and have briefly been described in their report.

2.1 Apparatus

Three circular test cylinders of different diameters are equipped with one of the five varying ellipsoidal obstructions on their leading edge, to form the main part of the experimental apparatus. Uniform heat flux is provided to the cylinders by two AC transformers.

2.1.1 Wind Tunnel

The wind tunnel used in the study is a low speed, open circuit, suck down arrangement of the Eiffel type, with an overall length of 9.5 m.

It is made of plywood, and consists of six separate sections: entrance, contraction, test section, diffuser, flexible coupling, and a fan. The 1.53m × 2.44m entrance section has four screens, made of 1.4mm mesh size. All screens are clamped together. The 2.14m long contraction section has a contraction ratio of 4.0. The test section is 3.66m in length, with a rectangular cross-section of 0.91m × 0.61m. The rectangular diffuser with about a 6.5° angle is first converted to a regular octagon with a length of 2.29m, and then changed into a sixteen sided polygon, for a length of 1.07m. The flexible connection, made of about a 300mm wide rubber, is used to minimize the vibration originating from the function of fan.

The Buffalo axial fan has a diameter of 1.45m, and the maximum capacity of 25.5m³/s, at about 89mm water head. The fan motor has a full load of 27.6 kw with a maximum r.p.m of 1170 and is controlled by an adjustable speed magnetic drive.

The front side of the working section of the wind tunnel has been equipped with a quick-release window which facilitates fast access to the test section, while the test process is observed through its transparent plexiglas.

2.1.2 Test Assembly: the Cylinder and the Step

Three circular test cylinders and five semi-ellipsoidal obstructions, Tables 2.1 and 5.2, were used. The configurations of the test assembly, arranged for the

three settings of experiment, is going to be explained in the present chapter. Meanwhile Figure 2.1 details the cylinder-step assembly.

Step

The steps were machined in diameters of 2.0, 2.5, 3.0, 4.0, and 5.0 inches, from a plastic material, Derlin. The semi-elliptical outline of the obstruction, halved on its longer axis, has the general equation of :

$$\left(\frac{x}{D}\right)^2 + \left(\frac{r}{D/2}\right)^2 = 1 \quad (2.1)$$

The maximum blockage effect, arising from the frontal area of the largest step at $D = 5 \text{ in.}$, is calculated to be:

$$\frac{\frac{\pi}{4}(13 \times 10^{-2})^2(\text{area section of step})}{0.91 \times 0.61(\text{area of tunnel at test section})} = 2.5\% \quad (2.2)$$

Therefore, no blockage correction has been done.

Test Cylinders

The test cylinders were available from the earlier experiments done by Kim et al. (1990). The cylinders have been selected from commercially available Atlas 304 seamless stainless steel tubing, in three sizes of 0.5, 1.0, and 2.0 inches. The thermal conductivity(k) and the thermal expansion of Atlas 304 are respectively given as $16.3W/m.^{\circ}C$, and $17.3 \times 10^{-6}cm/cm.^{\circ}C$ for the range of 0 to $100^{\circ}C$. After a set of trial experiments on the formerly used test tubes, the areas of interest on the wall where the points of maximum heat transfer lie were identified. Based on this knowledge, a new configuration for the thermocouple wires was worked out (Table 2.2), with a more

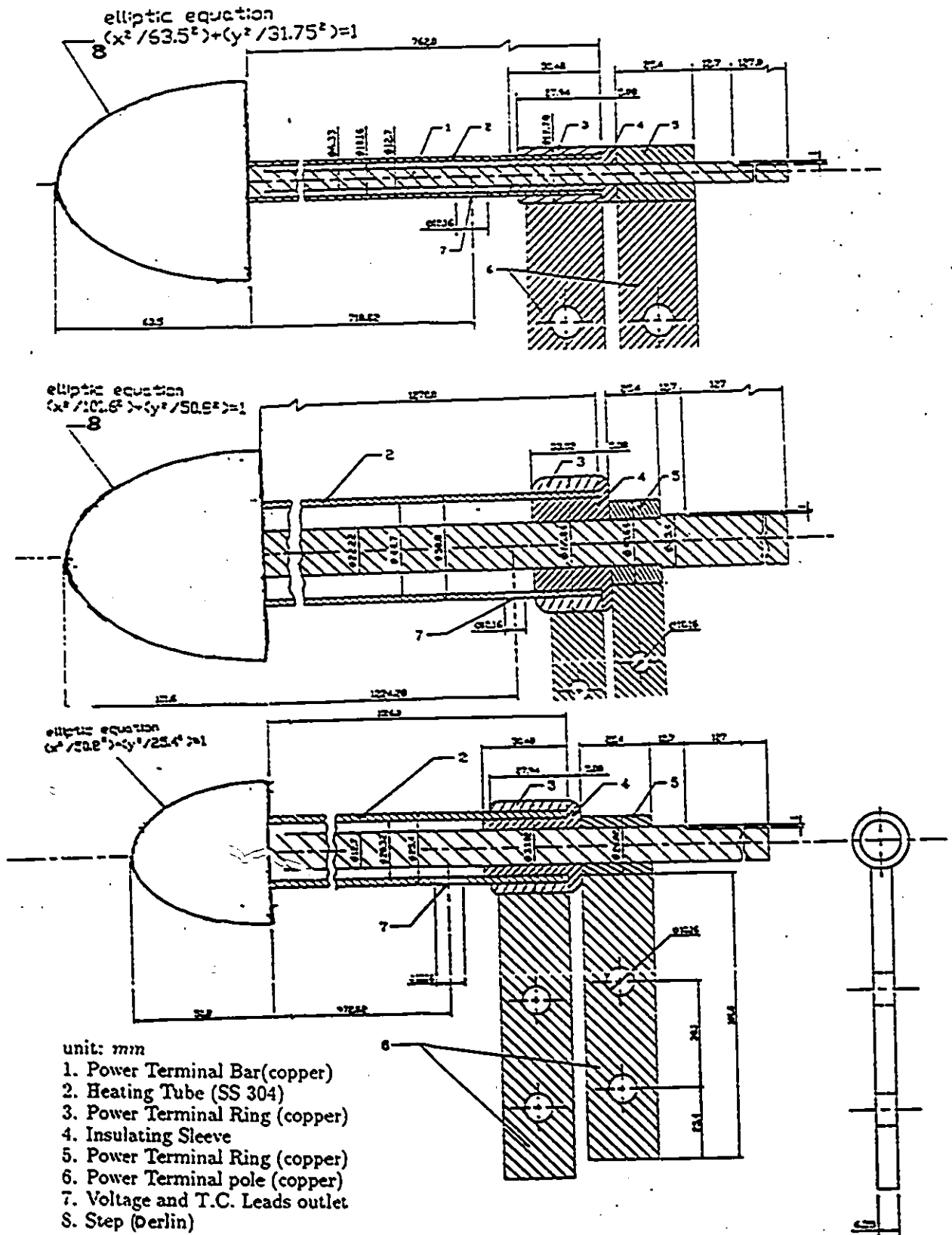


Figure 2.1: Assembly details of the cylinder, step, and power terminal bar in three cases of $d = 0.5''$, $D = 2.5''$; $d = 1''$, $D = 2''$; and $d = 2''$, $D = 4''$)

| $d, in.$ | d_o, mm | d_i, mm | L, mm |
|----------|-----------|-----------|---------|
| 0.5 | 12.7 | 10.9 | 762 |
| 1.0 | 25.4 | 20.6 | 889 |
| 2.0 | 50.8 | 44.7 | 1016 |

Table 2.1: Measurements of the test cylinders

closely spaced probes in the neighborhood of the points of maximum heat transfer and within the recirculation region. According to the new design, up to twenty five pairs of Copper-Constantan thermocouples (T-type), with a gauge size of 30, were installed along the inner wall periphery of the test cylinders.

The test assemblies were positioned in the wind tunnel, with the line of the thermocouples upward, using two kinds of supporting fixtures; one rigid and fixed for the downstream and the other free and adjustable at the upstream.

The rigid support is a modified steel "I" beam, having the weight reduced by boring holes in the web.

For the upstream supporting fixture, the finest available commercial guitar string, type PL007, made of plain steel with a diameter of 0.18mm was used. One pair of guitar headsets, fixed on a bracket, is installed on both corners of the outer roof of the wind tunnel to control the equilateral tension in the string. Figure 2.2 shows the test assembly inside the wind tunnel.

The supporting string, passing around the neck of the test assembly, was embedded in a very tiny groove existing between the cylinder and the step,

| $d(in.)$ | 0.5 | 1 | 2 |
|----------|----------|----------|----------|
| probes | $X(in.)$ | $X(in.)$ | $X(in.)$ |
| 1 | 0.5 | 0.5 | 0.5 |
| 2 | 1 | 1 | 1 |
| 3 | 2.5 | 1.5 | 2 |
| 4 | 3 | 2 | 2.5 |
| 5 | 3.5 | 2.5 | 3 |
| 6 | 4 | 3 | 4 |
| 7 | 5 | 3.5 | 4.5 |
| 8 | 6 | 4 | 5 |
| 9 | 8 | 4.5 | 5.5 |
| 10 | 15 | 5 | 6 |
| 11 | 25 | 5.5 | 6.5 |
| 12 | 30 | 6 | 7 |
| 13 | | 7 | 8 |
| 14 | | 7.5 | 10 |
| 15 | | 8 | 12 |
| 16 | | 9 | 16 |
| 17 | | 10 | 20 |
| 18 | | 11 | 25 |
| 19 | | 12 | 30 |
| 20 | | 15 | 35 |
| 21 | | 16 | 40 |
| 22 | | 20 | |
| 23 | | 25 | |
| 24 | | 30 | |
| 25 | | 35 | |

Table 2.2: The configuration of thermocouple probes along the wall of the cylinders

and attached to the rear face of the step, and was equally tightened, from both sides, to the roof of the wind tunnel.

The variation of Reynolds number, based on the diameter of the string, for the range of free stream velocity in the experiments, i.e. $U = 5$ to 30m/s , is calculated to be in the range 50 to 300. This range, according to the chart of the Strouhal number ($\frac{nd}{U}$) versus the Reynolds number for flow past a circular cylinder (Jones, 1968), corresponds to a maximum vortex shedding frequency of about $33,000\text{ Hz}$.

2.2 Instrumentation and Data Acquisition

The data acquisition system used in the study consists of a Hewlett-Packard (HP) desk top computer with four other HP instruments: HP 3455A digital Voltmeter, HP 3495A Scanner, HP 7245A Printer/Plotter, and HP 98035 Real Time Clock. Figure 2.3 details the set up of experiment and instrumentation.

The system was set up to analyze the signals received from the measuring instruments, and to calculate the required data via a computer program, Program E.1, written in the BASIC language for the HP machine system.

2.2.1 Measurement of Velocity

The pressure signal from the pitot static-tube was measured with two MKS Baraton pressure transducers, which have full scale pressure heads of 133.4pa (1Torr), and 1.334kPa (10Torr) respectively with a resolution of not more

than 0.1% at full scale. An alcohol-filled inclined micromanometer has been used to obtain the calibration factor of each pressure transducer by means of a plot of readings from the pressure transducer versus measured velocities from manometer.

The pitot-static tube has been installed in alignment with the test cylinders, axially slightly farther upstream of the step and vertically halfway between the roof of the wind tunnel (20cm below) and the test cylinder (24cm above), which could be seen from Figure 2.2.

In addition, in the present wind tunnel, the fluctuation of velocity at $U = 36 \text{ m/s}$ was measured (Maillet and Tjan, 1975) to be 7%.

2.2.2 Measurement of Temperatures

As it was explained before, the longitudinal temperature distributions on the wall of cylinder were measured by installing thermocouple wires along its inner wall periphery. The probes were chosen from #30 AWG, "T" type (copper-constantan) thermocouple wire which has a diameter of 0.0050 in. .

A terminal strip bar, installed outside the wind tunnel, facilitates the transmission of the thermocouple voltage to the scanner through #20 AWG copper wires (Figure 2.3). The thermocouple and copper wires were manufactured by Honeywell and were enamel-cotton insulated.

All pairs of thermocouple wires were soft soldered flush with the surface of cylinder. Figure 2.4 shows the method used in installation of the thermocouple wires. The thermocouple leads were then pulled through the inner space between the copper power terminal bar and the heating tube (cylinder).

to the outside. The outlet of the leads is shown in Figure 2.1 .

The spacing between the adjacent couples was smallest near the upstream end of the cylinder, where the separation bubbles exist; the details are tabulated in Table 2.2 .

Due to the high level of friction between the wires at the time of pulling them through the small inner space, which may cause damage or breakage, the number of wires in each cylinder is very limited. This did not allow a more closely spaced installation of probes in the wall of cylinder.

The axisymmetry of the temperature distribution has been verified on the formerly used test cylinders, by three pairs of probes radially affixed 120° apart from each other— at the same axial station. The verification has been confirmed, as will be discussed later, in the course of flow visualization, too.

The free stream temperature was measured by a pair of thermocouple wires, selected from the same type used for wall temperature distribution. The wire was installed on the stem of the pitot-tube located upstream of the step. The wire was then pulled out of the roof of wind tunnel to the data acquisition system.

The uncertainty of the temperature reading, for the working range of 20 to 40°C in the present study, is estimated at $\pm 0.8^\circ\text{C}$ (Omega, 1985).

2.2.3 Heat Flux

The stainless steel wall of the test cylinder acts as a resistance heating element. Because of the requirement for a high electric current, the power to the test cylinders was supplied via two "AC" transformers in series. The

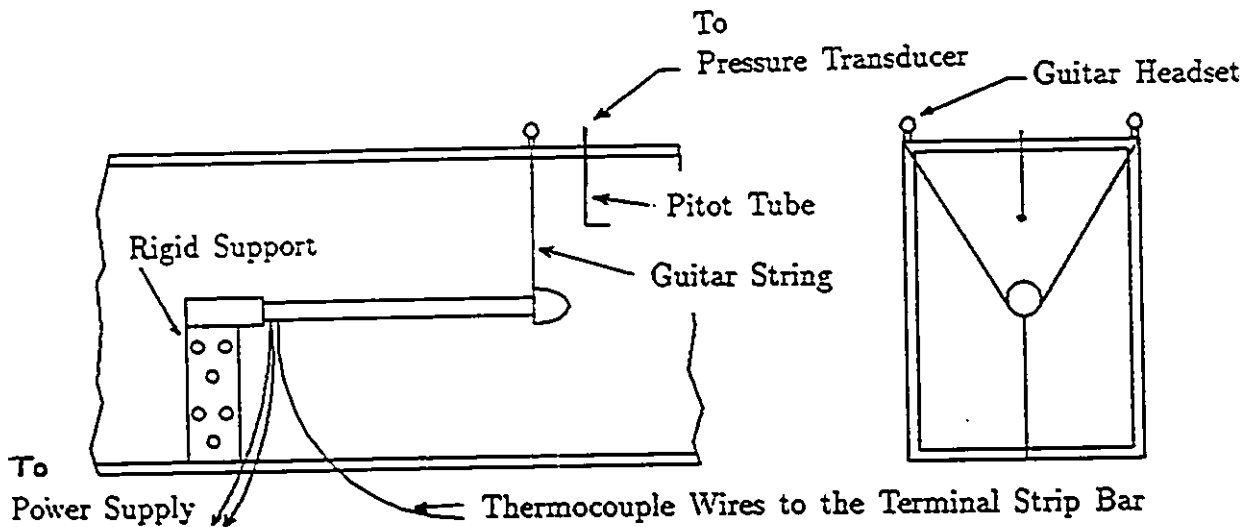


Figure 2.2: Schematic of the test assembly inside the test section of the wind tunnel, held by a rigid support and guitar string

primary was fed by a manually controlled 0 to 240 Volt autotransformer.

The electric current used for calculation of the dissipated power, as is shown on Figure 2.3, was measured by a loop current transformer, hooked around the outlet of the second transformer, and a multirange ammeter.

In addition, the voltage drop between the first and last probes on the test cylinder were measured by an extra pair of copper wires connected to the first and last contacts on the terminal bar. The wires are sketched by dashed-lines in figure 2.3 . The measured voltage drop (v) along with the current reading (i) will be used for the heat flux ($q = vi$) calculation.

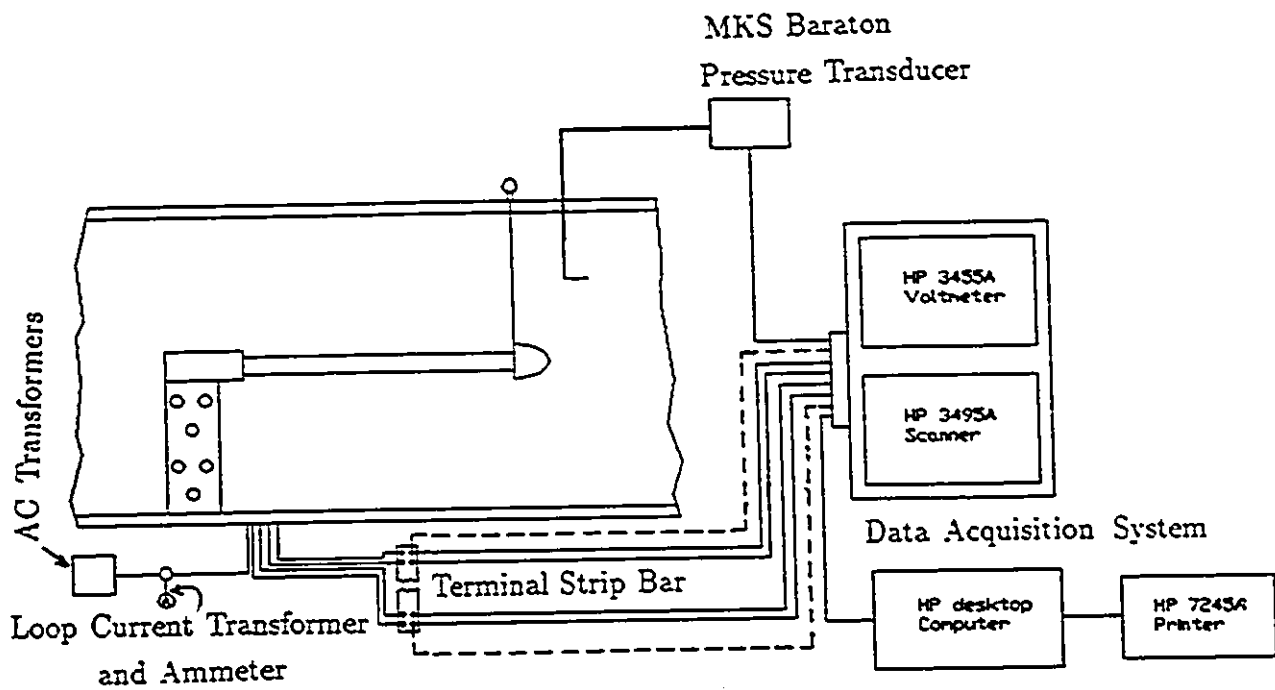


Figure 2.3: Schematic of the experimental set up and instrumentation

N.B.: Dashed-lines represent an extra pair of copper wires for measuring the voltage drop between the first and last probes.

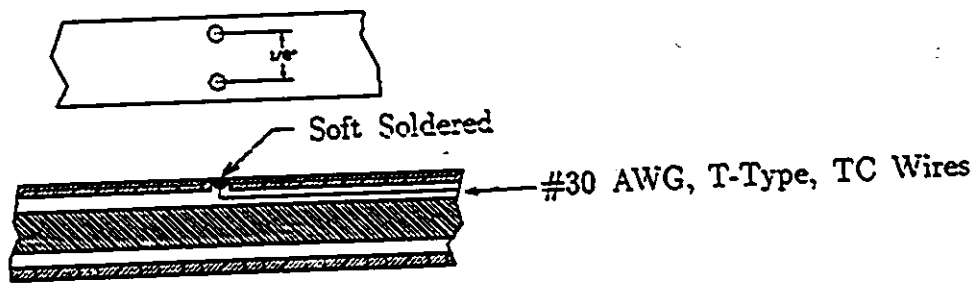


Figure 2.4: Top and sectional views of the test cylinder showing the installation of thermocouple wires by "Split Hot-Junction Method", (Lee, 1964)

Chapter 3

Experimental Procedure

The experiment has been performed for seven geometric cases, defined by the three test cylinders with diameters of 0.5, 1, and 2 inches along with the five steps of diameters 2, 2.5, 3, 4, and 5 inches. The set up is presented in Table 5.2 . Each of the above seven cases was in turn executed at sixteen velocities ranging from 5 to 30 *m/s*.

The output data is retyped into the mainframe computer (CMS) for further processing using the "Fortran (Watfor77)" compiler. The data and calculated results are tabulated in Appendix A.

The alignment of the test assembly (cylinder-step), with respect to the main air flow was checked using a surveying level and a 3-hole yaw tube.

3.1 Commissioning of the Experimental Apparatus

A program, listed in Appendix E, has been compiled which issues instruction commands at each step to let the user proceed with the experiment. The processing of the experimental data, typed by the user, leads to the computing of heat transfer parameters and axial temperature distributions.

At the initial step, the typed-in temperature($^{\circ}C$) and pressure ($mm\ Hg$) of the lab, read respectively from a mercury-filled thermometer and barometer, are used by the data acquisition system to compute density (ρ) and viscosity (μ) of the air. The relation for perfect gas ($\rho = P/RT$) has been applied to obtain ρ ; μ was interpolated from available tables of air properties.

In addition, a similar program had earlier been used to calibrate the pressure transducer against an alcohol-filled micromanometer, at different speeds of the wind tunnel.

3.2 Measurement of Velocity

Before proceeding to the velocity measurement, the pressure taps of the pitot-tube are connected to either the low or the high pressure transducer, depending on whether the velocity is less or more than $15\ m/s$.

A zero reading adjustment of the pressure transducer in still air must be performed before each turning-on of the wind tunnel, for which the instruction is issued by the data acquisition system. Up to one hour of idle running

| | | | | | | | | |
|---------------|-------|------|------|-------|-------|-----|--------|----|
| order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| velocity(m/s) | 15(A) | 20 | 25 | 30(A) | 12.5 | 10 | 7.5(A) | 5 |
| order | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| velocity(m/s) | 30(B) | 27.5 | 22.5 | 17.5 | 15(B) | 8.7 | 7.5(B) | 6 |

Table 3.1: Example of the velocity change order, case of $d = 2^n$, $S = 1^n$

N.B.: (A) and (B) denote respectively the first and second trials in each of the three velocity cases of 7.5, 15, and 30m/s

of the wind tunnel is required to attain a steady state at the desired velocity, with an uncertainty of ± 0.3 m/s.

For each of the seven geometric cases (Table 5.2) of the study, a similar set of sixteen velocities, varying between 5 to 30m/s, have been tried; the trials for $U = 30$, 15, and 7.5m/s were repeated in order to verify their reproducibility.

3.3 Measurement of Wall Temperature Distribution

A similar procedure to that which has been accomplished to achieve a steady state upstream velocity was followed for the desired level of steady state temperature on the surface of the cylinder, by adjusting the current from the primary transformer. The transformer was regulated to maintain the difference between the temperatures of free stream and surface below 20°C . A fluctuation amount of $\pm 0.05^\circ\text{C}$ was considered sufficient as a criterion for

the steady state condition of temperature distribution. The fluctuation is the difference between two consecutive temperature readings of each axial point on the wall of cylinder.

The read-out current was entered in the data acquisition system, and the "AC" voltage difference between the first and last probes was measured to calculate the surface heat flux ($q = v \dot{t}$).

The recorded date and time on top of every data table indicates that each of the two repeated or successive velocity cases have not been executed sequentially, in order to avoid a time lag in the steady state of temperature gradient. It was noticed that whenever the velocity is changed slightly to the next step, due to a time lag, an excessive period of time is required to attain the steady state of temperature gradient. The problem is resolved if a bigger velocity step change be selected in both increasing and decreasing directions. As a sample, Table 3.1 shows the order of velocity change for the case of $d = 2''$, $S = 1''$.

3.4 Flow Visualization

A new surface-streamline technique, proposed by Langston and Boyle (1982) for a low-speed wind tunnel, was used to detect the point of reattachment. The technique provides permanent traces of ink which show the direction and shape of the surface streamlines of the flow. The technique has been chosen from among different conventional options, such as tuft probes and oil-dye mixtures painted on the surface, to get a recorded surface-flow direction and surface-streamline pattern. However, the more sophisticated devices such as

thermal tuft or pulsed wall probes, described in Subsection 1.2.3 "Distinction Between . . .", are not commercially available for use on a curved surface.

Although the technique was extensively described and discussed by Langston and Boyle (1982) who developed the method, the steps specific to the present experiment, and the comments and observation resulted from the study, are mentioned here and also in Chapter 5 "Results and Discussion".

The test assembly was equipped with a strip of transparent film of 0.1 *mm* thickness and of adequate length to cover fully the cylinder from the leading edge up to beyond the point of maximum heat transfer and to the inside of the redeveloping boundary layer. The lateral edges of the film form an axial flush-seam line on the bottom of cylinder.

The film strip was affixed to the surface of the cylinder by using double-sided tape of 0.15 *mm* thickness. The film was fully grid-dotted by a black color, permanent-ink, felt-tipped pen (Staedtler Lumocolor 615). The dots were placed on the film 0.25 *in.* apart from each other in the vicinity of the reattachment point and .5 *in.* for the rest.

In the next step, oil of wintergreen was applied and the quick-release window on the test section of the wind tunnel was replaced. The same steps, which were explained in the former section under "Commissioning of the Experimental Apparatus", were repeated to attain the desired velocity.

Chapter 4

Data Reduction

Using the outputs of the data acquisition system, containing information such as the wall temperature distribution, magnitudes of flow and heat transfer parameters, the data files were set up, in the mainframe computer system (CMS), at the University of Ottawa. The files in turn were processed using Fortran programs run by the Watfor77 compiler. Samples of files and programs are documented in Appendix E .

Moreover, the output tables have the necessary input commands in order to be read by a word processor, Latex, and to generate a quality output of the complete set of result tables, as are found in Appendix A.

4.1 Cylinder-Step Case Study

The data tables for all of the seven geometric cases were regrouped, based on each of the three parameters d , D , and S , as is evident from the Table 5.2 .

Each group was processed by a Fortran program. The outputs were used for the case study on the effect of each parameter. The required graphs were produced by using the graphics software Disspla.

4.2 Axial Conduction Heat Transfer Rate

To take account of all of the three modes of heat transfer in computing the local heat transfer coefficient (h), Kim et al. (1990) have used the following equation:

$$h_x = \frac{\dot{q} + (k \frac{d^2t}{dx^2})b}{t - T} - \epsilon\sigma(t^2 + T^2)(t + T) \quad (4.1)$$

Based on the assumption of one-dimensional axial heat conduction, the equation was obtained from an energy balance made on the element of the test cylinder as follows:

$$\dot{q} = \dot{q}_{convection} + \dot{q}_{conduction} + \dot{q}_{radiation} \quad (4.2)$$

$$\dot{q} = h_x d(T - t) - kb \frac{d^2t}{dx^2} + \epsilon\sigma(t^4 - T^4) \quad (4.3)$$

It is needed to recall that the radiation term with respect to the range of temperature in the present study is negligible.

In addition, based on the assumption of a thin wall cylinder, the radial heat conduction was ignored. Moreover, the term $kb \frac{d^2T}{dx^2}$ presents the net axial conduction.

To compute the axial conduction heat transfer rate on the wall of the cylinder, and consequently the coefficient of heat transfer (h) for each of the seven cases, a discretization approach was applied. Equation 4.2 (Patankar,

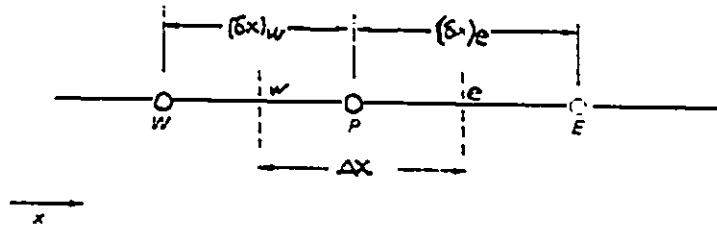


Figure 4.1: Scheme of the one dimensional non-equally spaced grid points

1980) is proposed as a model for the non-equally spaced configuration of thermocouples in the present study. Figure 4.1 depicts the schematic of the problem for the axial distribution of three neighbouring temperature nodes on the wall of cylinder.

$$\frac{d^2 T}{dx^2} = \frac{2}{(\delta x)_e + (\delta x)_w} \left[\frac{T_E - T_P}{(\delta x)_e} - \frac{T_P - T_W}{(\delta x)_w} \right] \quad (4.4)$$

To allow the start up of the numerical computation, the temperature of the free stream was initiated as the virtual first node, due to lack of a probe at the corner of cylinder and step. Therefore, for the first node on the upstream of cylinder, the computed value of the axial conduction rate ($kb \frac{d^2 T}{dx^2}$), and consequently, the calculated magnitudes of the heat transfer parameters may be considered illegitimate. Thus, the related blocks in the first row of the Tables A.1 to A.112 were left blank.

4.3 Local Heat Transfer Parameters

The local heat transfer coefficient (h_x) is deduced from Equation 4.1. The surface heat flux is directly calculated by the data acquisition system:

$$q = \frac{v i}{\pi d L} \quad (4.5)$$

Moreover, the dimensionless parameters for the heat transfer rate were defined as follows:

$$St = \frac{h}{\rho C_p U} \quad (4.6)$$

$$Nu_S = \frac{hS}{k_f} \quad (4.7)$$

$$Nu_d = \frac{hd}{k_f} \quad (4.8)$$

The uncertainty of each parameter, as is documented in Appendix C, was calculated to be about 17%.

$$Cond\% = \frac{kb \frac{dT}{dx}}{q} \quad (4.9)$$

This relation is used to calculate the ratio of the axial conduction heat to the total heat flux. Regarding the level of temperature variation, 20 °C, in the present set of experiments, for the above-mentioned equations and other calculations, the parameters C_p , k_f , and k_s were assumed constant; thus, the first two, C_p and k_f , have directly been extracted from the standard tables of air, and the last was inquired from the merchant of Atlas steel in Montreal, Russel Drummond (514-747-9881). For all of the 300 series stainless steels $K = 17.3 \frac{W}{m \cdot ^\circ C}$. However, other parameters, like ρ_{air} , ρ_{Hg} , and ν , as is evident from Appendix E (Program E.1), have been extrapolated from corresponding standard tables at room temperature, using the data acquisition system.

4.4 Correlation of Peak Heat Transfer Rate

In quest of an optimum correlation for the peak heat transfer rate, a subroutine for linear regression using the least squares method was created. Based on the existing correlated equations in the literature, and calculating the regression factor as a scale for evaluation, a trial and correction approach has been attempted to obtain the best fit relation for Nu_S with respect to $\frac{d}{D}$ and Re_S .

Furthermore, the correlation equations for each of the seven geometric cases were listed at the top of each page in Tables A.113 to A.119, to facilitate comparing them to each other and to the overall equation as well. The precision of exponents in the correlation equations was determined to be of two significant numbers of figure, using $I = \frac{s}{N^{1/2}(\ln Re_{max} - \ln Re_{min})}$. This index of uncertainty (I) was suggested by Richardson (1962).

Chapter 5

Results and Discussion

The set of data and results of the present experiment are tabulated in Appendix A. The set is divided into *three groups*, starting with 112 tables for all of the 7 cylinder-step cases, each reproduced for 16 different velocity tables. The second group summarizes the data and results for the point of the peak heat transfer rate in seven case tables, and finally, Appendix A is terminated with the records of observation from the separate set of experiments for flow visualization.

Although a summarized survey of the studies of some other researchers have been cited in Chapter 1, under the section "Background Study", attempts towards comparing their diversified numerical results with those of the present study, due to difference in the geometry of flow or wall, led nowhere. The flow geometries of the reviewed cases were found non-applicable to the present study. Furthermore, no paper was found studying the effect of step change on heat transfer in an external flow.

However, the lack of a theoretical solution of fluid flow within the separation region and in the reattachment point restricts the description and interpretation of the heat transfer at the solid boundaries.

It is also known that the parameters which characterize the downstream flow in the separation region are quite numerous. These parameters affect the energy exchange between the solid boundary and flow, and have already been specified in Section 1.2.3 .

5.1 General Features and Classification

For all of the seven step-cylinder geometry cases, a fairly good agreement among the results has been noticed with respect to each other. Note that the normalized magnitudes of the heat transfer parameters $\frac{Nuc}{Nu_{S,max}}$, $\frac{Nud}{Nu_{d,max}}$, and $\frac{St}{St_{max}}$ are equal to each other and to $\frac{h}{h_{max}}$. Figure B.7 shows the results for the three cylinders, each in seven velocity trials.

Generally, as documented in Appendix B, all graphs of the heat transfer versus a normalized length scale display features similar to all of the other works that were discussed in the literature review of Chapter 1.

A short length, corner located region in numerical results of heat transfer and fluid parameters was noticed by other researchers on external (Vogel and Eaton, 1985) and internal flows (Baughn et al., 1984). The region is characterized by having a decreasing heat transfer rate. The feature suggests the presence of a counter-rotating eddy trapped in the corner, beneath the larger and more active recirculating flow region. However, in the present study the number of thermal probes in the region is not sufficient to detect

| |
|--|
| $.41 \times 10^4 < Re_S < .11 \times 10^6$ |
| $.41 \times 10^4 < Re_d < .99 \times 10^5$ |
| $.41 \times 10^6 < Re_{x, \text{separation region}} < .30 \times 10^8$ |
| $.20 \times 10^7 < Re_{x, \text{redeveloping region}} < .20 \times 10^9$ |

Table 5.1: Variation of Reynolds numbers based on different Length Scales

this phenomenon.

Apart from the short, corner-located region of counter-rotating eddies, the heat transfer rate undergoes a steep monotonic rise, and immediately after a monotonic fall, then tends towards a constant magnitude. The “peak” of this commonly observed rise and fall infers *the point of maximum heat transfer*. The point may approximately signify a boundary between the separation boundary layer and the redeveloping one.

The decrease of heat transfer rate in the redeveloping boundary layer indicates a reduction in diffusion of turbulent kinetic energy produced at the wall, and re-development of the boundary layer may hypothetically be assumed to be coincident with the fall in heat transfer. This smooths out at 5 to 6 times D away from the X_{max} .

For all experiments, the variation of Reynolds numbers, based on the upstream velocity ranging between 5.4 to 30 m/s, is calculated in Table 5.1 .

| Case Study | cylinder/step size |
|-----------------|---------------------------------------|
| While $S = 1''$ | $d = 0.5'', 1'', \text{ and } 2''$ |
| While $D = 4''$ | $d = 0.5'', 1'', \text{ and } 2''$ |
| While $d = 1''$ | $D = 2'', 3'', 4'', \text{ and } 5''$ |

Table 5.2: Categories of Study based on Cylinder-Step Configuration

5.2 Effect of Each Single Geometric Parameter

Combining the result tables, produced from all of the seven cylinder-step configurations, leads to three cases with respect to involvement of the three different geometry parameters. The categorization, as is evident from the itemized list in Table 5.2, is set up based on varying one of the wall geometric parameters, each time, while the others were kept unchanging. However, no test has been tried to examine the effect of change in the apex angle of the nose of the obstruction on the downstream flow, which has been identified by Ota and Kon (1979). This has already been discussed in Section 1.2.3 "Distinction between ...".

5.2.1 Effect of Transverse Convex Curvature

The plots of the Nusselt number (Nu_S) versus the normalized axial length of the cylinder (X/D and X/S), as shown in Figures B.1 and B.2, depict the effect of transverse convex curvature on heat transfer and the reattachment length for the two cases of fixed step diameter ($D = 4 \text{ in.}$) and fixed step

height ($S = 1$ in.) at different velocities.

Effect of Transverse Convex Curvature on Heat Transfer

The present results are qualitatively in agreement with those of the previous experimental and theoretical studies on the transverse convex curvature (TVC) effect (Lee et al., 1993; Kim et al., 1990).

It is seen that the heat transfer rate at a given Reynolds number, and for the cases of both fixed step height and fixed step diameter, decreases as the diameter of the cylinder increases. The reason may be found in the fact that a decrease in curvature is a tendency towards the flat plate, or in other words, a transition from a case of axisymmetric geometry down to that of a two dimensional. In such a geometry shift towards a flat plate, at a given distance from the wall, the bulk of the working flow exposed to the surface area of the wall reduces as the radius of curvature increases. This may lead to a reduction in heat removed by the flow from the wall.

While the trend of the results in terms of the effect of TVC on heat transfer was found similar to that of Kim et al. (1990), no attempt has been made to compare the two results. Note that the streamlined-face circular cylinder without step (case of Kim et al., 1990) merely develops a unique boundary layer with a rather short length separation bubble which may be ignored. This implies a qualitatively different flow pattern on a stepless cylinder compared to the present study (Figure 5.1). In addition, the calculation of the heat transfer parameters based on the step size (S) makes it impossible to compare the present study with any stepless case, for both streamlined

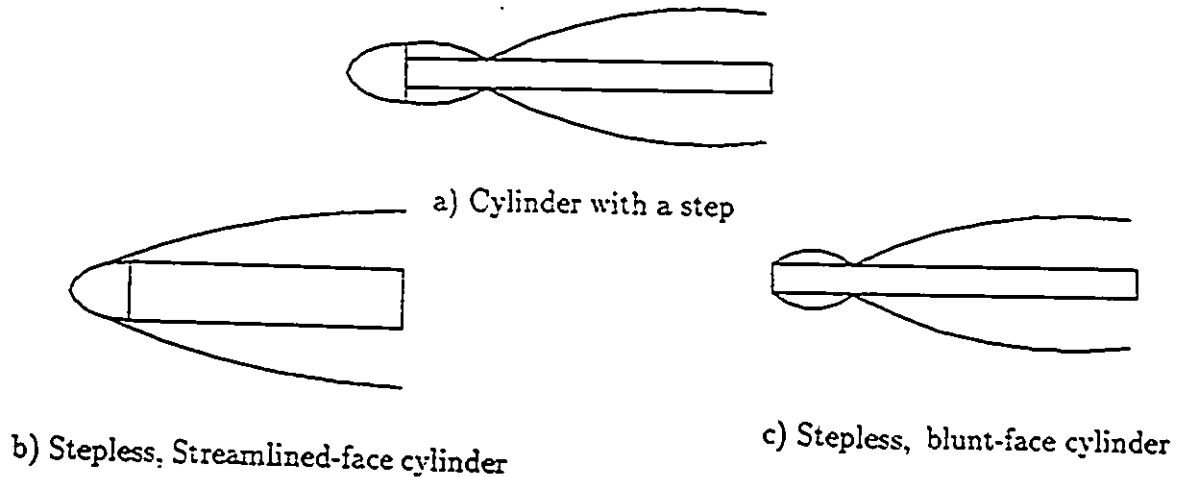


Figure 5.1: Flow separation and boundary layers in different cylinder-step geometries

and blunt face cylinders.

The non-applicability of the *step size* as a heat transfer scale parameter to the stepless circular cylinders —where $S = 0$ — may encourage switching from S to a fraction of the more universal parameter D (the diameter of step), such as $\frac{D}{2}$. Note that in a stepless cylinder $D = d$.

Effect of Transverse Convex Curvature on Loci of Maximum Heat Transfer (X_{max}) and Reattachment (X_r)

No effect of transverse convex curvature on the reattachment length was discovered. As will be discussed in Section 5.2 “Points of Reattachment...”, for the present study, the points of reattachment and maximum heat transfer may be assumed coincident, within an uncertainty of 0.5 in. . According to Figure B.2, at a constant upstream velocity where the step height is fixed ($S = 1''$), the length of the separation bubble increases when the diameters of cylinder (d), and step (D) concurrently increase. To distinguish the role

of each parameter from the other, Figure B.1 can be consulted too, where the diameter of cylinder is changing at a constant D . The point of maximum heat transfer occurs at about $1.25 D$ from the step, in all cases. This graph demonstrates that convex curvature has no effect the location of the point of maximum heat transfer, at least for the present set of experiments. Note that the change in step size (S) results from the change in d at constant step diameter. Obviously a constant curvature at the edge of the step (constant step diameter) implies on an *unchanging state* of the upstream separating flow in all cases.

5.2.2 Effects of Height and Diameter of the Step

Varying the step height, in four sizes, in increments of $0.5in.$ has been used for the case a of one inch diameter cylinder. Variation has been tried for $S = 0.5 in.$ up to $S = 2 in.$, and Figure B.3 is used to see how the heat transfer rate is changing. The plot of (Nu_S) at the fixed step diameter ($D = 4in.$) in Figure B.1 may also help to see how the change in step size influences the heat transfer rate.

The trend for both cases of the step height change and the step diameter change has been seen ~~to be alike~~, but different from that of convex curvature change. An increase of either one unit step size (S) or two units step diameter (D) has an equal effect on augmentation of the peak heat transfer rate and overall heat transfer along the test cylinder.

In spite of a concurrent arithmetic equation of $d = D - 2S$ among the three geometric parameters, it is not clear in which of the three parameters

the change has more impact on heat transfer rate. Nevertheless, Figure B.2 depicts the case where D increases according to an arithmetic progression, but d to a geometric one; the heat transfer changes in opposite to the trend of increasing D and in favour of the variation in d , i.e., decreases with the growth of d .

5.2.3 Effects of Aspect Ratio (D/d)

The plot of the $Nu_{S,max}$ versus D/d in Figure B.4 reveals a linear interrelation.

However, there is ambiguity in extrapolation of the graphs to $D/d \leq 1$ and $D/d = \infty$. The case of a flow approaching a streamlined (with no separation) or blunt face circular cylinder corresponds to $D/d = 1$, and separated flow leaving the trailing edge of a circular blunt base corresponds to $D/d = \infty$, where no solid surface may be imagined on which flow reattaches.

5.3 Entrainment and Correlation of the Effective Parameters

The plot of $Nu_{S,max}$ versus Re_S in Figure B.5 displays a consistent power correlation between the two parameters, as was the case in all of the articles reviewed and referred in Chapter 1.

As a first attempt at finding a correlation, a linear regression for $Nu_{S,max}$ versus Re_S and $Nu_{d,max}$ versus Re_d was computed for each of the seven cases. For every case, the correlated pair of equations is listed atop each of the

Tables A.113 to A.119 . The resulting equations are in a relative agreement with each other, and with those of the literature (Krall and Sparrow, 1966; Ota and Kon, 1977, 1974). The power of Re_S varies between 0.61 and 0.69 . For finding the power of Re_S , the results suggest trial and error in the vicinity of $2/3$.

To carry out the process, a subroutine for the least squares method was compiled, which also computes the regression factor, f . The absolute value of f from the worst to the best fit condition varies from 0 to 1.

A minute examination of different powers for Re_S , from ± 0.3 to ± 0.8 , and for d/D , from ± 0.1 to ± 0.4 , was concurrently tried in order to settle on the best fit regression. The process was terminated with:

$$Nu_{S,max} = 0.12 Re_S^{0.66} \left(\frac{d}{D}\right)^{-0.20} \quad (5.1)$$

The correspondence between each pair of the parameters is demonstrated in Figure B.6 , by the plots of $Nu_{S,max}$ versus Re_S , $Nu_{S,max}(d/D)^{0.20}$ versus Re_S , and $Nu_{S,max}(d/D)^{0.20}$ versus $Re_S^{0.66}$. In addition, the precision of exponents in the correlation equation was justified to two significant numbers, as was discussed in Section 4.4 "Correlation of ...".

Regarding the behaviour discussed for the flow geometry in the limiting cases of $D/d = 1$ and $D/d = \infty$, in Section 5.2.3 "Effects of Aspect Ratio", an upper and lower limit for D/d of a backward-facing step flow could be predicted, where the correlation is no more valid.

5.4 Flow Visualization

5.4.1 Application of the Technique

The application of the new technique of surface-streamline flow visualization, a sample of which is shown in Figure B.8, was partially successful in obtaining a qualitative interpretation on the state of the flow close to the wall surface.

The execution of the experiment on an unheated wall, according to Ota and Kon (1977), is not a matter of concern, as they verified the similarity of the flow characteristics under heated and unheated wall conditions.

After applying the oil and turning on the wind tunnel, the oil-ink solution started to splash and to leave spontaneous and non-steady streaklines. The streaklines became stabilized and identical with wall streamlines, after the wind tunnel velocity was adjusted and reached the steady state. To show that this was the case and that the transient flow at the wind tunnel start up stage does not affect the steady state flow visualization picture, Langston et al. (1979) used an ink injection method as a check.

In any event, although the dots are not protuberances, but smooth to the touch, they are dissolved in the sprayed oil on the wall surface. Due to frictional forces, the air stream carries the oil with it, and the remaining streaky deposit of the pigment gives information on the direction of flow. However, a question arises as to the interpretation and reliability of these observations, because the presence of the oil film affects the boundary conditions for the air flow near the solid wall. Squire (1962) has developed an equation for the slow

viscous motion of the oil flow pattern, according to which the velocities of air and oil at the oil-air interface are equal to each other and are very small. Therefore, the boundary conditions are not changed too much compared to the situation if no oil were there.

Furthermore, the edges of the drafting film (0.1mm thickness) do not disturb the flow. The upstream edge was secured under the step and has no contact with flow. The downstream edge is located well beyond the reattachment area to avoid any change in flow within the reattaching boundary layer.

For some cases of the flow, and in the course of advancing the experiment and gaining experience, it was possible to spot the counter-rotating eddy region on the upstream portion of the film. However, attempts to evaluate the axisymmetry of the flow, through observing circumferentially uniform streaklines, was not always possible for all of the grid dots, due to the fact that the gravity force of the ink solution was larger than the shear force of the air flow.

The problems encountered in the experiment are the low shear stress in the low speed velocity cases, which makes difficult the mechanical interaction between the oil-ink solution and the flow, the effect of gravity on the direction of the streaklines, the tedious work of applying sufficiently thick ink on the film.

A slight physical change in the plasticity of the polyester film towards brittleness was noticed, with kinking on the longitudinal edges, due probably to its reaction with the oil of wintergreen (Methyl salicylate). The change sometimes caused splitting of the mat at the time of detaching it from the

wall. To reduce breakage, the use of thin rubber bands, available in stationery stores, is recommended instead of double-sided adhesive tape.

Although the wind tunnel was kept running, it has often took a considerable amount of time to let the oily streaklines on the film dry. Installing a flexible glove on the wall of the test section, through which one can approach the test assembly with an injector or sprayer, may facilitate the appropriate application of less oil. The remedy will also reduce the deterioration of plasticity in the polyester, since the plastic mat would be exposed to a less harmful solution, within a shorter time period.

5.4.2 Points of Reattachment (X_r) and Maximum Heat Transfer (X_{max})

As stated previously, the test for the determination of the point of reattachment (X_r) has been carried out separately, on an unheated wall cylinder at room temperature, by using the flow visualization technique described. The results have been tabulated in Appendix A, Table A.120 to A.126, along with the values for X_{max} .

For all cases of the experiment, within an uncertainty of 0.5 in., X_r has been found to be equal to X_{max} . Sparrow et al. (1987), however, in an attempt to investigate the relation between the locations of reattachment and maximum heat transfer points, have found that for the case of flow where $X_r = X_{max}$, the separation bubble has a medium length. They have also categorized long and short length separation bubbles with respectively $X_r > X_{max}$, and $X_r < X_{max}$.

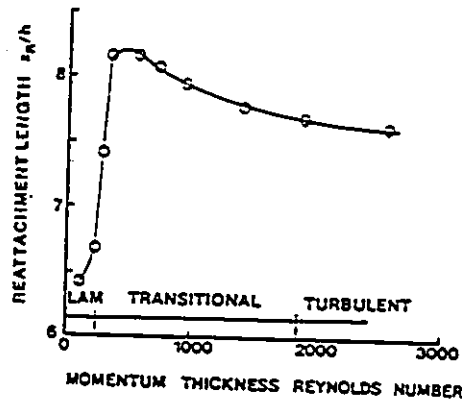


Figure 5.2: Dependence of the reattachment length on the state of the separation boundary layer (Eaton and Johnston, 1981)

In examining the results, as are presented in Tables A.120 to A.126, no orderly relation was observed between the growth of either S/d or D/d and the change in X_r or X_{max} . For the same values of S/d or D/d , but different cylinder diameters (d), there are conflicting results in the values of X_r or X_{max} . In the other words, no correlation could be discovered, in the present study, for X_r or X_{max} with respect to any parameters of wall geometry or flow. Moreover, the other researchers, in their literature reviews (Eaton and Johnston, 1981; Fletcher et al., 1974), have explicitly mentioned the existence of this seeming inconsistency.

The variance in reattachment length is connected to many parameters, mainly from the upstream flow field, yet to be formulated. Recall that Eaton and Johnston (1981) have listed five principal independent system parameters: The state and the thickness of the boundary layer at the separation edge, the free stream turbulence, the streamwise pressure gradient, and the aspect ratio of the flow apparatus.

Figure 5.2 depicts the reattachment length as a function of the state of the upstream separating flow. By using Figure 5.2, the nonorderly variations of the present results may be referred to the change in the momentum thickness Reynolds number of the separating flow at the edge of the step, due to the change in the step diameter.

In the present study, by increase of upstream velocity, within the range of 7.5 to 30 m/s , and in all cases of the present experiment, the loci of X_r and X_{max} move slightly upstream (their lengths become shorter), which is opposite to the conclusion of Sparrow et al. (1987), who showed a direct dependence of both points on Re when $Re < 30,000$, and their invariance when $Re > 30,000$. The reason for this paradox may be found in the study of Eaton and Johnston (1981), according to which, as is shown in Figure 5.2, the reattachment length X_r grows steeply with an increase in the Reynolds number of the laminar upstream flow, and then slightly decreases at the shift into transition flow. The flow apparently becomes independent of the Reynolds number when the separation boundary layer is fully turbulent.

5.5 Axial Conduction Heat Transfer

Although it was not aimed to study the results of computation for conduction heat transfer, a tentative analysis of some aspects, using the figures in the last column of the Tables A.1 to A.120, will be tried.

The axial temperature gradient on the wall of cylinder implies the existence of axial heat conduction. The conduction is considered to be a source of deviation from a pure convection; it also causes a non-uniform heat flux on

the surface of cylinder. However, there are questions arising from the effect of non-uniform heat flux caused by non-uniform temperature distribution or axial conduction on the wall of cylinder.

It may be presumed that axial conduction violates the uniformity of the distributed heat flux on the wall of cylinder. In reviewing the experimental results of numerous researches on heat transfer in separated flows, Richardson (1963) examined the dependence of the heat transfer rate upon the Reynolds number and other relevant factors, and found no significant difference between the cases in which the surface under separated flow was isothermal and those in which it was not. Furthermore, in an experimental study on non-isothermally heated cylinder and weighing the results against the predicted results for the isothermally heated cylinders, Eichhorn et al. (1958) have presented a close agreement between the two cases.

Therefore, it may be concluded that the present study does not lose its generality due to the non-uniformity of temperature distribution or heat flux.

Chapter 6

Conclusion

Axisymmetric and incompressible separated, reattached, and redeveloped turbulent flows were passed longitudinally over different constantly heated cylinders equipped with various ellipsoidal-nose backward steps. The heat transfer rate was calculated through the axial temperature distribution on the cylinder, measured by thermocouples. The axial conduction heat transfer was numerically computed. A surface-streamline flow visualization technique was applied to detect the point of reattachment.

Based on the present experimental study, the following concluding remarks may be drawn:

1. The backward-facing flow pattern on a solid wall is usually composed of two qualitatively different boundary layers separated from each other at the reattachment point:
 - i The first, known as the "separation bubble" or "recirculation region", stretches from the edge of the step, where it breaks

away, up to the point where it reattaches on the wall of the cylinder.

- ii The second one hereafter redevelops, and covers a relatively longer length of the wall.

The convective heat transfer in the recirculating region grows steeply to its maximum in the vicinity of the reattachment point, and then, after a sharp fall, smooths down to a fully developed magnitude.

2. A strong similarity was observed, in relation to the heat transfer parameters, among the different cases of the present study.
3. The effect of the *transverse convex curvature* on heat transfer for the axial turbulent flow was verified.
 - i The study confirms that the Nusselt number increases as the value of the cylinder diameter decreases, under any step-cylinder diameter ratio.
 - ii The transverse convex curvature has no effect on the reattachment length.
4. In contrast with the transverse curvature effect, an increase in height or diameter of the step enhances the heat transfer, yet it has been noticed that the effect of diameter of the cylinder, i.e., convex curvature, is more pronounced than that of the step, where the diameters of both were increased.

5. A growth in step diameter slightly elongates the reattachment length, for the range of upstream velocity in the present experiment.
6. A surface-streamline flow visualization technique was used to locate the point of reattachment.
 - i For the limited cases of the present study, designed for investigating the heat transfer characteristics, the results of the flow visualization test are insufficient for finding a correlation between the points of reattachment (X_r) and maximum heat transfer (X_{max}) with respect to S , D , and d .
 - ii For the set of present experiments X_r and X_{max} almost coincide, within an uncertainty of 0.5in..
 - iii Both points, nevertheless, move upstream, i.e., the length of the separation bubble shrinks, as a result of an upstream velocity increase from 7.5 to 30m/s.
 - iv As a conclusion, just as shown in Figure 5.2, and inasmuch as refers to the literature review, the reattachment length is dependent on the state of the separating boundary layer
7. A correlation among $Nu_{S,max}$, d/D , and Re_S has been developed as follows:

$$Nu_{S,max} = 0.12 Re_S^{0.66} \left(\frac{d}{D}\right)^{-0.20} \quad (6.1)$$

References

J.W. Baughn, M.A. Hoffman, R.K. Takahashi, and B.E. Launder, *Local Heat Transfer Downstream of an Abrupt Expansion in a Circular Channel with Constant Wall Heat Flux*, J. of Heat Transfer, vol. 106(1984), pp. 789-796.

T. Cebeci and A.M.O. Smith, *Analysis of Turbulent Boundary Layers*, Academic Press, New York (1974), pp. 227-232.

P.K. Chang, *Separation of Flow*, Pergamon, Oxford (1970).

J.K. Eaton and J.P. Johnston, *A Review of Research on Subsonic Flow Reattachment*, AIAA Journal, vol. 19(1981), pp. 1093-1100.

J.K. Eaton, R.V. Westphal, and J.P. Johnston, *Two New Instruments for Flow Direction and Skin-Friction Measurements in Separated Flows*, ISA Trans., vol. 21(1982), pp. 69-78.

H.U. Eckert *Simplified Treatment of the Turbulent Boundary Layer along a Cylinder in Compressible Flow*, J. of the Aeronautical Sciences, vol. 22(1952), pp. 23-29.

E. Eichhorn, E.R.G. Eckert, and A.D. Anderson, *An Experimental Study of the Effects of Non-uniform Wall Temperature on Heat Transfer in Laminar and Turbulent Axisymmetric Flow along a Cylinder*, WADC TR 58-33(July 1958), pp. 1-11.

L.S. Fletcher, D.G. Briggs, and R.H. Page, *Heat Transfer in Separated and Reattached Flows: an Annotated Review*, Israel Journal of Technology, vol. 12(1974), pp. 236-261.

A.F. Ghoniem and J.A. Sethian, *Effect of Reynolds Number on the Structure of Recirculating Flow*, AIAA Journal, vol. 25(1987), pp. 168-171.

G.W. Jones Jr., *Unsteady Lift Forces Generated by Vortex Shedding about a Large, Stationary, and Oscillating Cylinder at High Reynolds Numbers*, Symp. Unsteady Flow, ASME(1968); quoted from *Engineering Fluid Mechanics*, by J.A. Roberson and C.T. Crowe, Houghton Mifflin, Boston(1985), Ch. 11.

K.C. Kim, Y. Lee, and E. Ma, *Effect of Transverse Convex Curvature on Turbulent Flow and Heat Transfer*, Proc. 1st Int. Symposium on Experimental & Computational Aerothermodynamics of Internal Flows, (Beijing, 1990), pp. 202-207.

S.J. Kline and F.A. McClintock, *Uncertainties in Single-Sample Experiments*, Mechanical Engineering, vol. 75(1953), pp. 3-9.

K.M. Krall and E.M. Sparrow, *Turbulent Heat Transfer in the Separated, Reattached, and Redevelopment Regions of a Circular Tube*, J. of Heat Transfer, vol. 88(1966), pp. 131-136.

L.S. Langston and M.T. Boyle, *A new Surface-Streamline Flow Visualization Technique*, J. Fluid Mech., vol. 125(1982), pp. 53-57.

L.S. Langston, M.L. Nice, and R.M. Hooper, *Three Dimensional Flow within a Turbine Cascade Passage*, J. engng for power, vol. 99(1977), pp. 21-28; quoted from *ibid*.

Y. Lee, *Turbulent Flow and Heat Transfer in Concentric and Eccentric Annuli*, Ph.D. Thesis, Univ. of Liverpool(1964), Ch. 4.

Y. Lee and K.C. Kim, *An Analysis on Effect of Transverse Convex Curvature on Turbulent Flow and Heat Transfer*, Wärme- und Stoffübertragung, vol. 28(1993), pp. 89-95.

M. Maillet and D. Tjan, *Boundary Layer Growth over Cylinders having Smooth and Rough Surfaces*, B.A.Sc. thesis, Department of Mechanical Engineering, University of Ottawa, Ottawa, Canada(1975).

W. Merzkirch, *Flow Visualization*, Academic Press, Orlando, Fl. (1987), Ch. 2.

Omega Engineering Ltd., *Temperature Measurement Handbook and Encyclopedia*, Omega Press, Stamford, Conn. (1985), Section "T".

T. Ota, *An Axisymmetric Separated and Reattached Flow on a Longitudinal Blunt Circular Cylinder*, J. of Applied Mechanics, (June 1975), pp. 311-315.

T. Ota and N. Kon, *Heat Transfer in the Separated and Reattached Flow over Blunt Flat Plates —Effect of Nose Shape*, Int. J. Heat Mass Transfer, vol. 22(1979), pp. 197-206.

T. Ota and N. Kon, *Heat Transfer in an Axisymmetric Separated and Reattached Flow Over a Longitudinal Blunt Circular Cylinder*, J. of Heat Transfer, vol. 99(1977), pp. 155-157.

T. Ota and N. Kon, *Heat Transfer in the Separated and Reattached Flow on a Blunt Flat Plate*, J. of Heat Transfer, vol. 96(1974), pp. 459-462.

S.V. Patankar, *Numerical Heat Transfer and Fluid Flow*, Hemisphere, Washington, D.C. (1980), Ch. 3.

P.D. Richardson, *Heat and Mass Transfer in Turbulent Separated Flows*, Chemical Engineering Science, vol. 18(1963), pp. 149-155.

F.W. Roos and J.T. Kegelman, *Structure and Control of Flow over a Backward-Facing Step*, Forum on Unsteady Flow Separation, ASME-FED, vol. 52(1987), pp. 215-223.

A.J. Smith and D.H. Wood, *Response of Turbulent Boundary Layers to Sudden Perturbations*, Ann. Rev. Fluid Mech., vol 17(1985), pp. 321-358.

E.M. Sparrow, E.R.G. Eckert, and W.J. Minkowycz, *Heat Transfer and Skin Friction for Turbulent Boundary-Layer Flow Longitudinal to a Circular Cylinder*, J. of Applied Mechanics, March 1963, pp. 37-43.

E.M. Sparrow, S.S. Kang, and W. Chuck, *Relation between the Points of Flow Reattachment and Maximum Heat Transfer for Regions of Flow Separation*, Int. J. Heat Mass Transfer, vol. 30(1987), pp. 1237-1246.

L.C. Squire, *The Motion of a Thin Oil Sheet under the Boundary Layer on a Body*, AGARDograph AGARD-AG-70, pp. 7-28; quoted from *Flow Visualization*, by W. Merzkirch, Academic Press, Orlando, Fl. (1987), Ch. 2.

H. Suzuki, S. Kida, T. Nakamae, and K. Suzuki, *Flow and Heat Transfer over a Backward-facing Step with a Cylinder mounted near its top corner*, Int. J. of Heat and Fluid Flow, vol.12, No.4(Dec. 1991), pp. 353-359.

F. Tsou, S. J. Chen, and W. Aung, *Starting Flow and Heat Transfer Downstream of a Backward-Facing Step*, J. of Heat Transfer, vol. 113(1991), pp. 583-589.

Yun-Sheng Yu, *Effect of Transverse Curvature on Turbulent Boundary Layer Characteristics*, J. of Ship Research, vol. 2(1958), pp. 33-51.

P. Vaitiekunas, A. Zukauskas, and J. Ziugzda, *Numerical Modeling of Separated Flow Over and Heat Transfer from a Circular Cylinder or a*

Plate in Longitudinal Flow of Air, Heat transfer-Soviet Research, vol. 23(1991), pp. 291-305.

J.C. Vogel and J.K. Eaton, *combined Heat Transfer and Fluid Dynamic Measurements Downstream of a Backward-Facing Step*, J. of Heat Transfer, vol. 107(1985), pp. 922-929.

P.P. Zemanick and R.S. Dougall, *Local Heat Transfer Downstream of Aprupt Circular Channel Expansion*, J. of Heat Transfer, vol. 92(1970), pp. 53-60.

Appendix A

Tables of Data and Results

A.a Overall Data and Results for All of the 7 Cases

A.a-i Data and Results for 0.5" cylinder in Different Velocities; $S = 1''$

Case: 5twa-30a

Date and time of experiment: Oct.24,1992, 22:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.3 | | | | | | |
| 2 | 2.54 | 36.1 | 140. | .391E-02 | .137E+03 | .683E+02 | 2.48 | |
| 3 | 6.35 | 32.5 | 206. | .576E-02 | .201E+03 | .101E+03 | 2.20 | |
| 4 | 7.62 | 32.3 | 215. | .603E-02 | .210E+03 | .105E+03 | 3.35 | X_{max} |
| 5 | 8.89 | 32.7 | 202. | .565E-02 | .197E+03 | .986E+02 | 2.08 | |
| 6 | 10.16 | 33.6 | 180. | .505E-02 | .176E+03 | .881E+02 | 0.05 | |
| 7 | 12.70 | 35.4 | 152. | .425E-02 | .148E+03 | .742E+02 | 0.48 | |
| 8 | 15.24 | 36.8 | 136. | .381E-02 | .133E+03 | .665E+02 | 0.41 | |
| 9 | 20.32 | 38.5 | 121. | .338E-02 | .118E+03 | .590E+02 | 0.14 | |
| 10 | 38.10 | 40.6 | 105. | .295E-02 | .103E+03 | .515E+02 | 0.03 | |
| 11 | 63.50 | 41.3 | 101. | .284E-02 | .991E+02 | .496E+02 | 0.01 | |
| 12 | 76.20 | 41.4 | 101. | .283E-02 | .988E+02 | .494E+02 | 0.00 | |

Table A.1: .5 in. cylinder with $S=1$ in.; $U = 30.1(m/s)$, $T = 23.6(^{\circ}C)$, $q = 1791(W/m^2)$, $i = 58.0(A)$

Case: 5twa-30b

Date and time of experiment: Oct.25,1992, 01:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.4 | | | | | | |
| 2 | 2.54 | 36.3 | 139. | .390E-02 | .136E+03 | .681E+02 | 2.51 | |
| 3 | 6.35 | 32.7 | 206. | .576E-02 | .201E+03 | .101E+03 | 2.15 | |
| 4 | 7.62 | 32.4 | 216. | .603E-02 | .211E+03 | .105E+03 | 3.35 | X_{max} |
| 5 | 8.89 | 32.8 | 204. | .570E-02 | .199E+03 | .995E+02 | 2.31 | |
| 6 | 10.16 | 33.7 | 181. | .507E-02 | .177E+03 | .884E+02 | 0.02 | |
| 7 | 12.70 | 35.5 | 153. | .427E-02 | .149E+03 | .745E+02 | 0.47 | |
| 8 | 15.24 | 36.9 | 136. | .382E-02 | .133E+03 | .666E+02 | 0.41 | |
| 9 | 20.32 | 38.6 | 121. | .338E-02 | .118E+03 | .590E+02 | 0.15 | |
| 10 | 38.10 | 40.7 | 106. | .296E-02 | .103E+03 | .516E+02 | 0.03 | |
| 11 | 63.50 | 41.5 | 101. | .283E-02 | .990E+02 | .495E+02 | 0.01 | |
| 12 | 76.20 | 41.5 | 101. | .283E-02 | .986E+02 | .493E+02 | 0.00 | |

Table A.2: .5 in. cylinder with $S=1$ in.; $U = 30.1(m/s)$, $T = 23.8(^{\circ}C)$, $q = 1792(W/m^2)$, $i = 58.0(A)$

Case:5twa-27.5

Date and time of experiment: Oct.24,1992, 23:55

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.1 | | | | | | |
| 2 | 2.54 | 35.0 | 126. | .389E-02 | .123E+03 | .615E+02 | 2.63 | |
| 3 | 6.35 | 31.7 | 185. | .569E-02 | .180E+03 | .901E+02 | 2.37 | |
| 4 | 7.62 | 31.4 | 191. | .591E-02 | .187E+03 | .935E+02 | 3.07 | X_{max} |
| 5 | 8.89 | 31.7 | 184. | .568E-02 | .180E+03 | .899E+02 | 2.74 | |
| 6 | 10.16 | 32.5 | 164. | .506E-02 | .160E+03 | .801E+02 | 0.07 | |
| 7 | 12.70 | 34.1 | 139. | .428E-02 | .136E+03 | .678E+02 | 0.46 | |
| 8 | 15.24 | 35.4 | 124. | .383E-02 | .121E+03 | .606E+02 | 0.45 | |
| 9 | 20.32 | 37.1 | 110. | .339E-02 | .107E+03 | .536E+02 | 0.16 | |
| 10 | 38.10 | 39.1 | 95. | .294E-02 | .932E+02 | .466E+02 | 0.04 | |
| 11 | 63.50 | 39.9 | 91. | .282E-02 | .893E+02 | .446E+02 | 0.01 | |
| 12 | 76.20 | 39.9 | 91. | .281E-02 | .891E+02 | .445E+02 | 0.00 | |

Table A.3: .5 in. cylinder with $S=1$ in.; $U = 27.3(m/s)$, $T = 23.3(^{\circ}C)$,
 $q = 1512(W/m^2)$, $i = 53.3(A)$

Case:5twa-25

Date and time of experiment: Oct.24,1992, 23:35

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.1 | | | | | | |
| 2 | 2.54 | 35.1 | 118. | .399E-02 | .115E+03 | .576E+02 | 3.11 | |
| 3 | 6.35 | 31.7 | 174. | .589E-02 | .170E+03 | .850E+02 | 2.46 | |
| 4 | 7.62 | 31.4 | 182. | .616E-02 | .178E+03 | .889E+02 | 3.59 | X_{max} |
| 5 | 8.89 | 31.8 | 174. | .588E-02 | .170E+03 | .848E+02 | 2.83 | |
| 6 | 10.16 | 32.6 | 154. | .522E-02 | .151E+03 | .753E+02 | 0.04 | |
| 7 | 12.70 | 34.2 | 130. | .441E-02 | .127E+03 | .637E+02 | 0.47 | |
| 8 | 15.24 | 35.6 | 116. | .394E-02 | .114E+03 | .569E+02 | 0.45 | |
| 9 | 20.32 | 37.3 | 102. | .347E-02 | .100E+03 | .500E+02 | 0.18 | |
| 10 | 38.10 | 39.5 | 89. | .300E-02 | .866E+02 | .433E+02 | 0.04 | |
| 11 | 63.50 | 40.2 | 85. | .286E-02 | .827E+02 | .413E+02 | 0.01 | |
| 12 | 76.20 | 40.3 | 85. | .286E-02 | .826E+02 | .413E+02 | 0.00 | |

Table A.4: .5 in. cylinder with $S=1$ in.; $U = 24.9(m/s)$, $T = 23.3(^{\circ}C)$,
 $q = 1436(W/m^2)$, $i = 52.0(A)$

Case:5twa-22.5

Date and time of experiment: Oct.25,1992, 00:10

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.9 | | | | | | |
| 2 | 2.54 | 35.8 | 111. | .414E-02 | .108E+03 | .542E+02 | 3.39 | |
| 3 | 6.35 | 32.2 | 165. | .615E-02 | .161E+03 | .806E+02 | 2.63 | |
| 4 | 7.62 | 31.9 | 173. | .644E-02 | .169E+03 | .843E+02 | 3.75 | X_{max} |
| 5 | 8.89 | 32.3 | 165. | .615E-02 | .161E+03 | .806E+02 | 3.05 | |
| 6 | 10.16 | 33.1 | 146. | .546E-02 | .143E+03 | .715E+02 | 0.12 | |
| 7 | 12.70 | 34.9 | 123. | .459E-02 | .120E+03 | .602E+02 | 0.48 | |
| 8 | 15.24 | 36.4 | 110. | .409E-02 | .107E+03 | .535E+02 | 0.48 | |
| 9 | 20.32 | 38.3 | 96. | .357E-02 | .937E+02 | .468E+02 | 0.19 | |
| 10 | 38.10 | 40.8 | 82. | .306E-02 | .803E+02 | .401E+02 | 0.05 | |
| 11 | 63.50 | 41.7 | 78. | .292E-02 | .764E+02 | .382E+02 | 0.02 | |
| 12 | 76.20 | 41.7 | 78. | .291E-02 | .763E+02 | .381E+02 | 0.00 | |

Table A.5: .5 in. cylinder with S=1 in.; $U = 22.6(m/s)$, $T = 23.3(^{\circ}C)$, $q = 1443(W/m^2)$, $i = 52.0(A)$

Case:5twa-20

Date and time of experiment: Oct.24,1992, 23:15

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 34.8 | | | | | | |
| 2 | 2.54 | 34.8 | 101. | .426E-02 | .984E+02 | .492E+02 | 3.76 | |
| 3 | 6.35 | 31.5 | 149. | .632E-02 | .146E+03 | .730E+02 | 2.90 | |
| 4 | 7.62 | 31.3 | 155. | .657E-02 | .152E+03 | .758E+02 | 3.78 | X_{max} |
| 5 | 8.89 | 31.6 | 149. | .630E-02 | .145E+03 | .727E+02 | 3.09 | |
| 6 | 10.16 | 32.3 | 133. | .563E-02 | .130E+03 | .650E+02 | 0.27 | |
| 7 | 12.70 | 33.9 | 112. | .476E-02 | .110E+03 | .549E+02 | 0.46 | |
| 8 | 15.24 | 35.3 | 100. | .423E-02 | .976E+02 | .488E+02 | 0.49 | |
| 9 | 20.32 | 37.1 | 87. | .369E-02 | .851E+02 | .426E+02 | 0.21 | |
| 10 | 38.10 | 39.6 | 74. | .314E-02 | .724E+02 | .362E+02 | 0.05 | |
| 11 | 63.50 | 40.5 | 70. | .298E-02 | .687E+02 | .344E+02 | 0.02 | |
| 12 | 76.20 | 40.5 | 70. | .298E-02 | .687E+02 | .343E+02 | 0.00 | |

Table A.6: .5 in. cylinder with S=1 in.; $U = 19.9(m/s)$, $T = 23.0(^{\circ}C)$, $q = 1229(W/m^2)$, $i = 48.0(A)$

Case:5twa-17.5

Date and time of experiment: Oct.25.1992, 00:40

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------------|
| 1 | 1.27 | 34.7 | | | | | | |
| 2 | 2.54 | 34.8 | 93. | .448E-02 | .910E+02 | .455E+02 | 4.21 | |
| 3 | 6.35 | 31.5 | 139. | .670E-02 | .136E+03 | .679E+02 | 3.02 | |
| 4 | 7.62 | 31.2 | 145. | .698E-02 | .142E+03 | .708E+02 | 3.79 | <i>X_{max}</i> |
| 5 | 8.89 | 31.4 | 141. | .678E-02 | .138E+03 | .688E+02 | 3.64 | |
| 6 | 10.16 | 32.2 | 126. | .605E-02 | .123E+03 | .614E+02 | 0.47 | |
| 7 | 12.70 | 33.8 | 106. | .508E-02 | .103E+03 | .516E+02 | 0.46 | |
| 8 | 15.24 | 35.2 | 93. | .450E-02 | .913E+02 | .457E+02 | 0.53 | |
| 9 | 20.32 | 37.1 | 81. | .390E-02 | .792E+02 | .396E+02 | 0.23 | |
| 10 | 38.10 | 39.8 | 68. | .327E-02 | .664E+02 | .332E+02 | 0.06 | |
| 11 | 63.50 | 40.9 | 64. | .308E-02 | .625E+02 | .312E+02 | 0.03 | |
| 12 | 76.20 | 40.9 | 64. | .308E-02 | .625E+02 | .312E+02 | 0.00 | |

Table A.7: .5 in. cylinder with S=1 in.; $U = 17.5(m/s)$, $T = 23.1(^{\circ}C)$, $q = 1138(W/m^2)$, $i = 46.3(A)$

Case:5twa-15a

Date and time of experiment: Oct.24,1992, 23:00

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------------|
| 1 | 1.27 | 34.9 | | | | | | |
| 2 | 2.54 | 35.1 | 80. | .451E-02 | .780E+02 | .390E+02 | 5.36 | |
| 3 | 6.35 | 31.8 | 118. | .670E-02 | .116E+03 | .579E+02 | 2.57 | |
| 4 | 7.62 | 31.3 | 127. | .719E-02 | .124E+03 | .622E+02 | 4.35 | <i>X_{max}</i> |
| 5 | 8.89 | 31.4 | 126. | .714E-02 | .123E+03 | .617E+02 | 4.27 | |
| 6 | 10.16 | 31.9 | 115. | .649E-02 | .112E+03 | .560E+02 | 1.20 | |
| 7 | 12.70 | 33.5 | 96. | .543E-02 | .939E+02 | .469E+02 | 0.31 | |
| 8 | 15.24 | 35.0 | 84. | .477E-02 | .824E+02 | .412E+02 | 0.58 | |
| 9 | 20.32 | 37.0 | 72. | .409E-02 | .707E+02 | .354E+02 | 0.28 | |
| 10 | 38.10 | 40.0 | 60. | .339E-02 | .587E+02 | .293E+02 | 0.07 | |
| 11 | 63.50 | 41.1 | 56. | .319E-02 | .551E+02 | .275E+02 | 0.03 | |
| 12 | 76.20 | 41.1 | 56. | .319E-02 | .551E+02 | .275E+02 | 0.00 | |

Table A.8: .5 in. cylinder with S=1 in.; $U = 14.9(m/s)$, $T = 23.9(^{\circ}C)$, $q = 1029(W/m^2)$, $i = 44.0(A)$

Case: 5twa-15b

Date and time of experiment: Oct.25,1992, 00:55

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 34.7 | | | | | | |
| 2 | 2.54 | 34.9 | 81. | .458E-02 | .791E+02 | .396E+02 | 5.29 | |
| 3 | 6.35 | 31.6 | 121. | .685E-02 | .118E+03 | .592E+02 | 2.83 | |
| 4 | 7.62 | 31.2 | 129. | .728E-02 | .126E+03 | .629E+02 | 4.18 | X_{max} |
| 5 | 8.89 | 31.3 | 127. | .719E-02 | .124E+03 | .621E+02 | 4.10 | |
| 6 | 10.16 | 31.9 | 115. | .651E-02 | .112E+03 | .562E+02 | 1.01 | |
| 7 | 12.70 | 33.4 | 97. | .548E-02 | .946E+02 | .473E+02 | 0.29 | |
| 8 | 15.24 | 34.9 | 85. | .481E-02 | .831E+02 | .416E+02 | 0.56 | |
| 9 | 20.32 | 36.9 | 73. | .413E-02 | .713E+02 | .357E+02 | 0.27 | |
| 10 | 38.10 | 39.9 | 60. | .342E-02 | .591E+02 | .295E+02 | 0.07 | |
| 11 | 63.50 | 41.0 | 57. | .320E-02 | .553E+02 | .276E+02 | 0.03 | |
| 12 | 76.20 | 41.0 | 57. | .320E-02 | .553E+02 | .276E+02 | 0.00 | |

Table A.9: .5 in. cylinder with $S=1$ in.; $U = 14.9(m/s)$, $T = 22.8(^{\circ}C)$,
 $q = 1030(W/m^2)$, $i = 44.0(A)$

Case: 5twa-12.5

Date and time of experiment: Oct.25,1992, 03:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.4 | | | | | | |
| 2 | 2.54 | 33.7 | 71. | .472E-02 | .690E+02 | .345E+02 | 6.67 | |
| 3 | 6.35 | 30.8 | 105. | .704E-02 | .103E+03 | .514E+02 | 2.54 | |
| 4 | 7.62 | 30.3 | 114. | .759E-02 | .111E+03 | .555E+02 | 4.38 | |
| 5 | 8.89 | 30.3 | 115. | .767E-02 | .112E+03 | .561E+02 | 5.08 | X_{max} |
| 6 | 10.16 | 30.8 | 104. | .698E-02 | .102E+03 | .510E+02 | 1.53 | |
| 7 | 12.70 | 32.2 | 88. | .585E-02 | .855E+02 | .428E+02 | 0.27 | |
| 8 | 15.24 | 33.5 | 77. | .514E-02 | .751E+02 | .375E+02 | 0.55 | |
| 9 | 20.32 | 35.5 | 65. | .437E-02 | .639E+02 | .319E+02 | 0.31 | |
| 10 | 38.10 | 38.4 | 53. | .357E-02 | .522E+02 | .261E+02 | 0.09 | |
| 11 | 63.50 | 39.6 | 50. | .332E-02 | .485E+02 | .242E+02 | 0.04 | |
| 12 | 76.20 | 39.6 | 50. | .333E-02 | .487E+02 | .243E+02 | 0.00 | |

Table A.10: .5 in. cylinder with $S=1$ in.; $U = 12.6(m/s)$, $T = 22.5(^{\circ}C)$,
 $q = 849(W/m^2)$, $i = 40.0(A)$

Case: 5twa-10

Date and time of experiment: Oct.25,1992, 02:45

| No. | X(cm) | T($^{\circ}$ C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|------------------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.7 | | | | | | |
| 2 | 2.54 | 34.1 | 61. | .518E-02 | .601E+02 | .300E+02 | 7.65 | |
| 3 | 6.35 | 31.1 | 92. | .771E-02 | .894E+02 | .447E+02 | 2.43 | |
| 4 | 7.62 | 30.6 | 100. | .846E-02 | .982E+02 | .491E+02 | 5.38 | |
| 5 | 8.89 | 30.5 | 101. | .854E-02 | .990E+02 | .495E+02 | 5.60 | X_{max} |
| 6 | 10.16 | 31.0 | 92. | .778E-02 | .903E+02 | .451E+02 | 1.83 | |
| 7 | 12.70 | 32.4 | 78. | .654E-02 | .758E+02 | .379E+02 | 0.14 | |
| 8 | 15.24 | 33.8 | 68. | .572E-02 | .663E+02 | .332E+02 | 0.54 | |
| 9 | 20.32 | 35.9 | 57. | .481E-02 | .558E+02 | .279E+02 | 0.37 | |
| 10 | 38.10 | 39.2 | 46. | .387E-02 | .449E+02 | .225E+02 | 0.11 | |
| 11 | 63.50 | 40.6 | 42. | .358E-02 | .415E+02 | .207E+02 | 0.05 | |
| 12 | 76.20 | 40.6 | 42. | .358E-02 | .415E+02 | .208E+02 | 0.00 | |

Table A.11: .5 in. cylinder with $S=1$ in.; $U = 10.0(m/s)$, $T = 22.5(^{\circ}C)$,
 $q = 769(W/m^2)$, $i = 38.0(A)$

Case: 5twa- 8.7

Date and time of experiment: Oct.25,1992, 03:25

| No. | X(cm) | T($^{\circ}$ C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|------------------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.6 | | | | | | |
| 2 | 2.54 | 34.0 | 55. | .532E-02 | .537E+02 | .268E+02 | 7.90 | |
| 3 | 6.35 | 31.0 | 81. | .787E-02 | .794E+02 | .397E+02 | 2.49 | |
| 4 | 7.62 | 30.5 | 89. | .865E-02 | .873E+02 | .436E+02 | 5.53 | |
| 5 | 8.89 | 30.4 | 91. | .882E-02 | .890E+02 | .445E+02 | 6.25 | X_{max} |
| 6 | 10.16 | 30.8 | 83. | .807E-02 | .814E+02 | .407E+02 | 2.20 | |
| 7 | 12.70 | 32.2 | 70. | .680E-02 | .686E+02 | .343E+02 | 0.00 | |
| 8 | 15.24 | 33.6 | 61. | .593E-02 | .598E+02 | .299E+02 | 0.61 | |
| 9 | 20.32 | 35.8 | 52. | .499E-02 | .504E+02 | .252E+02 | 0.39 | |
| 10 | 38.10 | 39.3 | 41. | .398E-02 | .402E+02 | .201E+02 | 0.12 | |
| 11 | 63.50 | 40.8 | 38. | .365E-02 | .369E+02 | .184E+02 | 0.06 | |
| 12 | 76.20 | 40.8 | 38. | .365E-02 | .368E+02 | .184E+02 | 0.00 | |

Table A.12: .5 in. cylinder with $S=1$ in.; $U = 8.7(m/s)$, $T = 22.2(^{\circ}C)$,
 $q = 703(W/m^2)$, $i = 36.0(A)$

Case:5twa-7.5a

Date and time of experiment: Oct.25,1992, 01:45

| No. | X(cm) | T($^{\circ}$ C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|------------------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.6 | | | | | | |
| 2 | 2.54 | 34.0 | 48. | .540E-02 | .470E+02 | .235E+02 | 9.22 | |
| 3 | 6.35 | 31.3 | 71. | .798E-02 | .694E+02 | .347E+02 | 2.22 | |
| 4 | 7.62 | 30.7 | 79. | .889E-02 | .773E+02 | .386E+02 | 6.04 | |
| 5 | 8.89 | 30.5 | 81. | .914E-02 | .795E+02 | .398E+02 | 7.00 | X_{max} |
| 6 | 10.16 | 30.9 | 75. | .840E-02 | .731E+02 | .365E+02 | 2.56 | |
| 7 | 12.70 | 32.1 | 64. | .714E-02 | .621E+02 | .311E+02 | 0.24 | |
| 8 | 15.24 | 33.4 | 55. | .623E-02 | .542E+02 | .271E+02 | 0.64 | |
| 9 | 20.32 | 35.5 | 47. | .524E-02 | .456E+02 | .228E+02 | 0.42 | |
| 10 | 38.10 | 39.1 | 37. | .415E-02 | .361E+02 | .180E+02 | 0.14 | |
| 11 | 63.50 | 40.6 | 34. | .380E-02 | .331E+02 | .165E+02 | 0.07 | |
| 12 | 76.20 | 40.6 | 34. | .380E-02 | .331E+02 | .165E+02 | 0.00 | |

Table A.13: .5 in. cylinder with $S=1$ in.; $U = 7.5(m/s)$, $T = 22.4(^{\circ}C)$,
 $q = 615(W/m^2)$, $i = 34.0(A)$

Case:5twa-7.5b

Date and time of experiment: Oct.25,1992, 04:00

| No. | X(cm) | T($^{\circ}$ C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|------------------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.1 | | | | | | |
| 2 | 2.54 | 33.4 | 49. | .549E-02 | .482E+02 | .241E+02 | 8.70 | |
| 3 | 6.35 | 30.7 | 73. | .809E-02 | .710E+02 | .355E+02 | 2.38 | |
| 4 | 7.62 | 30.1 | 80. | .894E-02 | .784E+02 | .392E+02 | 5.77 | |
| 5 | 8.89 | 30.0 | 82. | .917E-02 | .804E+02 | .402E+02 | 6.59 | X_{max} |
| 6 | 10.16 | 30.3 | 76. | .847E-02 | .743E+02 | .372E+02 | 2.75 | |
| 7 | 12.70 | 31.6 | 64. | .716E-02 | .628E+02 | .314E+02 | 0.17 | |
| 8 | 15.24 | 32.9 | 56. | .624E-02 | .547E+02 | .274E+02 | 0.61 | |
| 9 | 20.32 | 35.1 | 47. | .523E-02 | .459E+02 | .229E+02 | 0.43 | |
| 10 | 38.10 | 38.6 | 37. | .414E-02 | .363E+02 | .181E+02 | 0.14 | |
| 11 | 63.50 | 40.1 | 34. | .379E-02 | .333E+02 | .166E+02 | 0.07 | |
| 12 | 76.20 | 40.1 | 34. | .379E-02 | .333E+02 | .166E+02 | 0.00 | |

Table A.14: .5 in. cylinder with $S=1$ in.; $U = 7.5(m/s)$, $T = 22.0(^{\circ}C)$,
 $q = 615(W/m^2)$, $i = 34.0(A)$

Case: 5twa-06

Date and time of experiment: Oct.25,1992, 03:40

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.3 | | | | | | |
| 2 | 2.54 | 33.8 | 42. | .583E-02 | .406E+02 | .203E+02 | 10.53 | |
| 3 | 6.35 | 31.1 | 61. | .858E-02 | .597E+02 | .299E+02 | 2.17 | |
| 4 | 7.62 | 30.5 | 68. | .954E-02 | .664E+02 | .332E+02 | 6.04 | |
| 5 | 8.89 | 30.3 | 71. | .992E-02 | .690E+02 | .345E+02 | 7.59 | X_{max} |
| 6 | 10.16 | 30.6 | 66. | .921E-02 | .641E+02 | .320E+02 | 3.20 | |
| 7 | 12.70 | 31.8 | 56. | .789E-02 | .549E+02 | .274E+02 | 0.54 | |
| 8 | 15.24 | 33.1 | 49. | .687E-02 | .478E+02 | .239E+02 | 0.53 | |
| 9 | 20.32 | 35.3 | 41. | .572E-02 | .398E+02 | .199E+02 | 0.49 | |
| 10 | 38.10 | 39.1 | 32. | .447E-02 | .311E+02 | .155E+02 | 0.17 | |
| 11 | 63.50 | 40.8 | 29. | .408E-02 | .284E+02 | .142E+02 | 0.09 | |
| 12 | 76.20 | 40.8 | 29. | .408E-02 | .284E+02 | .142E+02 | 0.00 | |

Table A.15: .5 in. cylinder with $S=1$ in.; $U = 6.0(m/s)$, $T = 22.0(^{\circ}C)$,
 $q = 546(W/m^2)$, $i = 32.0(A)$

Case: 5twa-05

Date and time of experiment: Oct.25,1992, 02:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.4 | | | | | | |
| 2 | 2.54 | 33.9 | 36. | .608E-02 | .353E+02 | .176E+02 | 11.38 | |
| 3 | 6.35 | 31.4 | 53. | .886E-02 | .514E+02 | .257E+02 | 1.50 | |
| 4 | 7.62 | 30.7 | 60. | .101E-01 | .584E+02 | .292E+02 | 7.06 | |
| 5 | 8.89 | 30.4 | 62. | .105E-01 | .610E+02 | .305E+02 | 8.29 | X_{max} |
| 6 | 10.16 | 30.6 | 59. | .987E-02 | .572E+02 | .286E+02 | 4.00 | |
| 7 | 12.70 | 31.7 | 50. | .850E-02 | .493E+02 | .246E+02 | 0.88 | |
| 8 | 15.24 | 33.0 | 44. | .739E-02 | .428E+02 | .214E+02 | 0.53 | |
| 9 | 20.32 | 35.2 | 36. | .614E-02 | .356E+02 | .178E+02 | 0.54 | |
| 10 | 38.10 | 39.1 | 28. | .476E-02 | .276E+02 | .138E+02 | 0.20 | |
| 11 | 63.50 | 40.8 | 26. | .433E-02 | .251E+02 | .125E+02 | 0.11 | |
| 12 | 76.20 | 40.7 | 26. | .435E-02 | .253E+02 | .126E+02 | 0.02 | |

Table A.16: .5 in. cylinder with $S=1$ in.; $U = 5.0(m/s)$, $T = 22.1(^{\circ}C)$,
 $q = 479(W/m^2)$, $i = 30.0(A)$

A.a-ii Data and Results for 0.5" cylinder in Different Velocities; $D = 4"$

Case:5twb-20a

Date and time of experiment: Nov.2,1992, 24:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 34.3 | | | | | | |
| 2 | 2.54 | 35.4 | 125. | .345E-02 | .214E+03 | .610E+02 | 4.40 | |
| 3 | 6.35 | 33.3 | 155. | .428E-02 | .265E+03 | .757E+02 | 0.09 | |
| 4 | 7.62 | 32.6 | 164. | .453E-02 | .281E+03 | .801E+02 | 0.38 | |
| 5 | 8.89 | 31.8 | 179. | .494E-02 | .306E+03 | .873E+02 | 0.99 | |
| 6 | 10.16 | 31.3 | 190. | .524E-02 | .325E+03 | .927E+02 | 1.37 | |
| 7 | 12.70 | 31.0 | 195. | .538E-02 | .333E+03 | .951E+02 | 1.47 | X_{max} |
| 8 | 15.24 | 32.1 | 173. | .479E-02 | .297E+03 | .847E+02 | 0.17 | |
| 9 | 20.32 | 34.5 | 139. | .385E-02 | .239E+03 | .681E+02 | 0.18 | |
| 10 | 38.10 | 38.4 | 107. | .295E-02 | .183E+03 | .522E+02 | 0.06 | |
| 11 | 63.50 | 39.4 | 101. | .279E-02 | .173E+03 | .493E+02 | 0.01 | |
| 12 | 76.20 | 39.4 | 101. | .279E-02 | .173E+03 | .493E+02 | 0.00 | |

Table A.17: .5 in. cylinder with D=4 in.; $U = 30.0(m/s)$, $T = 21.7(^{\circ}C)$, $q = 1785(W/m^2)$, $i = 58.0(A)$

Case:5twb-30b

Date and time of experiment: Nov.3,1992, 02:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 34.8 | | | | | | |
| 2 | 2.54 | 36.1 | 119. | .332E-02 | .204E+03 | .582E+02 | 4.60 | |
| 3 | 6.35 | 34.0 | 146. | .407E-02 | .250E+03 | .715E+02 | 0.16 | |
| 4 | 7.62 | 33.4 | 152. | .424E-02 | .260E+03 | .743E+02 | 1.17 | |
| 5 | 8.89 | 32.5 | 168. | .469E-02 | .288E+03 | .823E+02 | 1.26 | |
| 6 | 10.16 | 31.9 | 179. | .498E-02 | .306E+03 | .874E+02 | 1.54 | |
| 7 | 12.70 | 31.6 | 183. | .509E-02 | .313E+03 | .894E+02 | 1.48 | X_{max} |
| 8 | 15.24 | 32.7 | 164. | .456E-02 | .280E+03 | .799E+02 | 0.19 | |
| 9 | 20.32 | 35.3 | 132. | .369E-02 | .227E+03 | .646E+02 | 0.18 | |
| 10 | 38.10 | 39.3 | 102. | .285E-02 | .175E+03 | .500E+02 | 0.07 | |
| 11 | 63.50 | 40.2 | 97. | .270E-02 | .166E+03 | .474E+02 | 0.01 | |
| 12 | 76.20 | 40.3 | 97. | .270E-02 | .166E+03 | .473E+02 | 0.00 | |

Table A.18: .5 in. cylinder with D=4 in.; $U = 30.0(m/s)$, $T = 21.6(^{\circ}C)$, $q = 1810(W/m^2)$, $i = 58.0(A)$

Case:.5twb-27.5

Date and time of experiment: Nov.3,1992, 01:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.4 | | | | | | |
| 2 | 2.54 | 34.5 | 115. | .347E-02 | .197E+03 | .561E+02 | 4.77 | |
| 3 | 6.35 | 32.6 | 141. | .426E-02 | .241E+03 | .688E+02 | 0.17 | |
| 4 | 7.62 | 31.9 | 150. | .454E-02 | .257E+03 | .733E+02 | 0.37 | |
| 5 | 8.89 | 31.2 | 165. | .498E-02 | .282E+03 | .805E+02 | 1.39 | |
| 6 | 10.16 | 30.6 | 174. | .525E-02 | .297E+03 | .848E+02 | 1.32 | |
| 7 | 12.70 | 30.4 | 180. | .543E-02 | .307E+03 | .877E+02 | 1.57 | X_{max} |
| 8 | 15.24 | 31.3 | 161. | .487E-02 | .276E+03 | .787E+02 | 0.24 | |
| 9 | 20.32 | 33.6 | 130. | .392E-02 | .222E+03 | .634E+02 | 0.18 | |
| 10 | 38.10 | 37.4 | 99. | .299E-02 | .169E+03 | .483E+02 | 0.07 | |
| 11 | 63.50 | 38.4 | 93. | .282E-02 | .159E+03 | .455E+02 | 0.02 | |
| 12 | 76.20 | 38.4 | 93. | .282E-02 | .159E+03 | .455E+02 | 0.00 | |

Table A.19: .5 in. cylinder with $D=4$ in.; $U = 27.4(m/s)$, $T = 21.4(^{\circ}C)$, $q = 1584(W/m^2)$, $i = 54.7(A)$

Case:.5twb-25

Date and time of experiment: Nov.3,1992, 02:10

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.1 | | | | | | |
| 2 | 2.54 | 34.1 | 108. | .359E-02 | .185E+03 | .527E+02 | 4.86 | |
| 3 | 6.35 | 32.3 | 133. | .443E-02 | .226E+03 | .650E+02 | 0.03 | |
| 4 | 7.62 | 31.7 | 140. | .467E-02 | .240E+03 | .686E+02 | 0.59 | |
| 5 | 8.89 | 30.9 | 154. | .514E-02 | .264E+03 | .754E+02 | 1.41 | |
| 6 | 10.16 | 30.4 | 163. | .542E-02 | .279E+03 | .796E+02 | 1.41 | |
| 7 | 12.70 | 30.2 | 168. | .559E-02 | .288E+03 | .821E+02 | 1.66 | X_{max} |
| 8 | 15.24 | 31.1 | 151. | .501E-02 | .258E+03 | .736E+02 | 0.26 | |
| 9 | 20.32 | 33.3 | 121. | .403E-02 | .207E+03 | .592E+02 | 0.19 | |
| 10 | 38.10 | 37.2 | 92. | .304E-02 | .157E+03 | .447E+02 | 0.08 | |
| 11 | 63.50 | 38.3 | 85. | .284E-02 | .146E+03 | .417E+02 | 0.02 | |
| 12 | 76.20 | 38.3 | 85. | .284E-02 | .146E+03 | .417E+02 | 0.00 | |

Table A.20: .5 in. cylinder with $D=4$ in.; $U = 24.9(m/s)$, $T = 21.5(^{\circ}C)$, $q = 1436(W/m^2)$, $i = 52.0(A)$

Case:.5twb-22.5

Date and time of experiment: Nov.3,1992, 01:30

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.3 | | | | | | |
| 2 | 2.54 | 34.5 | 103. | .376E-02 | .175E+03 | .501E+02 | 5.39 | |
| 3 | 6.35 | 32.6 | 127. | .466E-02 | .217E+03 | .620E+02 | 0.14 | |
| 4 | 7.62 | 32.0 | 133. | .486E-02 | .227E+03 | .648E+02 | 0.95 | |
| 5 | 8.89 | 31.2 | 145. | .533E-02 | .249E+03 | .711E+02 | 1.01 | |
| 6 | 10.16 | 30.6 | 155. | .570E-02 | .266E+03 | .759E+02 | 1.60 | |
| 7 | 12.70 | 30.3 | 162. | .593E-02 | .277E+03 | .790E+02 | 1.78 | X_{max} |
| 8 | 15.24 | 31.1 | 146. | .534E-02 | .249E+03 | .712E+02 | 0.34 | |
| 9 | 20.32 | 33.5 | 117. | .427E-02 | .199E+03 | .569E+02 | 0.19 | |
| 10 | 38.10 | 37.8 | 86. | .317E-02 | .148E+03 | .422E+02 | 0.08 | |
| 11 | 63.50 | 39.1 | 80. | .293E-02 | .137E+03 | .391E+02 | 0.03 | |
| 12 | 76.20 | 39.1 | 80. | .293E-02 | .137E+03 | .391E+02 | 0.00 | |

Table A.21: .5 in. cylinder with $D=4$ in.; $U = 22.6(m/s)$, $T = 21.4(^{\circ}C)$, $q = 1423(W/m^2)$, $i = 52.0(A)$

Case:.5twb-20

Date and time of experiment: Nov.3,1992, 00:55

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.5 | | | | | | |
| 2 | 2.54 | 34.7 | 93. | .386E-02 | .160E+03 | .455E+02 | 5.74 | |
| 3 | 6.35 | 33.0 | 113. | .469E-02 | .194E+03 | .553E+02 | 0.32 | |
| 4 | 7.62 | 32.3 | 120. | .495E-02 | .205E+03 | .584E+02 | 0.82 | |
| 5 | 8.89 | 31.5 | 132. | .546E-02 | .226E+03 | .644E+02 | 1.33 | |
| 6 | 10.16 | 30.9 | 140. | .582E-02 | .240E+03 | .686E+02 | 1.65 | |
| 7 | 12.70 | 30.5 | 147. | .610E-02 | .252E+03 | .720E+02 | 1.95 | X_{max} |
| 8 | 15.24 | 31.3 | 133. | .553E-02 | .228E+03 | .652E+02 | 0.43 | |
| 9 | 20.32 | 33.7 | 107. | .442E-02 | .183E+03 | .521E+02 | 0.20 | |
| 10 | 38.10 | 38.3 | 78. | .325E-02 | .134E+03 | .383E+02 | 0.09 | |
| 11 | 63.50 | 39.8 | 72. | .297E-02 | .123E+03 | .350E+02 | 0.03 | |
| 12 | 76.20 | 39.9 | 71. | .296E-02 | .122E+03 | .349E+02 | 0.01 | |

Table A.22: .5 in. cylinder with $D=4$ in.; $U = 20.0(m/s)$, $T = 21.3(^{\circ}C)$, $q = 1332(W/m^2)$, $i = 50.0(A)$

Case:5twb-17.5

Date and time of experiment: Nov.3,1992, 01:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 33.3 | | | | | | |
| 2 | 2.54 | 34.8 | 86. | .405E-02 | .147E+03 | .420E+02 | 7.00 | |
| 3 | 6.35 | 33.3 | 104. | .490E-02 | .178E+03 | .508E+02 | 0.62 | |
| 4 | 7.62 | 32.6 | 110. | .518E-02 | .189E+03 | .538E+02 | 1.01 | |
| 5 | 8.89 | 31.7 | 122. | .576E-02 | .210E+03 | .598E+02 | 1.68 | |
| 6 | 10.16 | 31.1 | 130. | .612E-02 | .223E+03 | .635E+02 | 1.74 | |
| 7 | 12.70 | 30.6 | 137. | .643E-02 | .234E+03 | .667E+02 | 2.03 | X_{max} |
| 8 | 15.24 | 31.4 | 124. | .585E-02 | .213E+03 | .607E+02 | 0.49 | |
| 9 | 20.32 | 33.8 | 100. | .470E-02 | .171E+03 | .488E+02 | 0.20 | |
| 10 | 38.10 | 38.6 | 73. | .342E-02 | .124E+03 | .355E+02 | 0.09 | |
| 11 | 63.50 | 40.5 | 65. | .307E-02 | .112E+03 | .319E+02 | 0.04 | |
| 12 | 76.20 | 40.6 | 65. | .306E-02 | .111E+03 | .317E+02 | 0.01 | |

Table A.23: .5 in. cylinder with $D=4$ in.; $U = 17.6(m/s)$, $T = 21.2(^{\circ}C)$,
 $q = 1259(W/m^2)$, $i = 48.7(A)$

Case:5twb-15a

Date and time of experiment: Nov.3,1992, 00:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 32.4 | | | | | | |
| 2 | 2.54 | 33.9 | 74. | .413E-02 | .126E+03 | .361E+02 | 7.66 | |
| 3 | 6.35 | 32.6 | 88. | .491E-02 | .150E+03 | .429E+02 | 0.77 | |
| 4 | 7.62 | 32.0 | 92. | .513E-02 | .157E+03 | .448E+02 | 1.73 | |
| 5 | 8.89 | 31.2 | 102. | .573E-02 | .175E+03 | .500E+02 | 1.64 | |
| 6 | 10.16 | 30.6 | 109. | .610E-02 | .187E+03 | .532E+02 | 1.75 | |
| 7 | 12.70 | 30.0 | 117. | .653E-02 | .200E+03 | .570E+02 | 2.38 | X_{max} |
| 8 | 15.24 | 30.6 | 108. | .603E-02 | .185E+03 | .527E+02 | 0.67 | |
| 9 | 20.32 | 32.7 | 87. | .489E-02 | .150E+03 | .427E+02 | 0.19 | |
| 10 | 38.10 | 37.3 | 63. | .353E-02 | .108E+03 | .308E+02 | 0.11 | |
| 11 | 63.50 | 39.2 | 56. | .316E-02 | .966E+02 | .276E+02 | 0.05 | |
| 12 | 76.20 | 39.3 | 56. | .314E-02 | .959E+02 | .274E+02 | 0.01 | |

Table A.24: .5 in. cylinder with $D=4$ in.; $U = 14.8(m/s)$, $T = 21.0(^{\circ}C)$,
 $q = 1028(W/m^2)$, $i = 44.0(A)$

Case:.5twb-15b

Date and time of experiment: Nov.3,1992, 02:55

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 32.5 | | | | | | |
| 2 | 2.54 | 33.9 | 76. | .422E-02 | .130E+03 | .370E+02 | 7.37 | |
| 3 | 6.35 | 32.6 | 90. | .502E-02 | .154E+03 | .440E+02 | 0.89 | |
| 4 | 7.62 | 32.0 | 95. | .528E-02 | .162E+03 | .463E+02 | 1.64 | |
| 5 | 8.89 | 31.2 | 106. | .593E-02 | .182E+03 | .520E+02 | 1.73 | |
| 6 | 10.16 | 30.5 | 114. | .635E-02 | .195E+03 | .557E+02 | 1.89 | |
| 7 | 12.70 | 30.0 | 122. | .680E-02 | .209E+03 | .596E+02 | 2.34 | X_{max} |
| 8 | 15.24 | 30.5 | 113. | .627E-02 | .193E+03 | .550E+02 | 0.71 | |
| 9 | 20.32 | 32.7 | 90. | .503E-02 | .155E+03 | .441E+02 | 0.20 | |
| 10 | 38.10 | 37.3 | 64. | .359E-02 | .110E+03 | .315E+02 | 0.11 | |
| 11 | 63.50 | 39.3 | 57. | .319E-02 | .980E+02 | .280E+02 | 0.05 | |
| 12 | 76.20 | 39.4 | 57. | .317E-02 | .974E+02 | .278E+02 | 0.01 | |

Table A.25: .5 in. cylinder with $D=4$ in.; $U = 15.0(m/s)$, $T = 21.3(^{\circ}C)$, $q = 1028(W/m^2)$, $i = 44.0(A)$

Case:.5twb-12.5

Date and time of experiment: Nov.3,1992, 04:50

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 31.9 | | | | | | |
| 2 | 2.54 | 33.4 | 68. | .442E-02 | .116E+03 | .331E+02 | 8.63 | |
| 3 | 6.35 | 32.5 | 79. | .517E-02 | .136E+03 | .387E+02 | 1.41 | |
| 4 | 7.62 | 31.8 | 83. | .543E-02 | .143E+03 | .407E+02 | 2.07 | |
| 5 | 8.89 | 31.0 | 94. | .614E-02 | .161E+03 | .460E+02 | 1.98 | |
| 6 | 10.16 | 30.3 | 101. | .656E-02 | .172E+03 | .491E+02 | 1.95 | |
| 7 | 12.70 | 29.7 | 109. | .709E-02 | .186E+03 | .531E+02 | 2.68 | X_{max} |
| 8 | 15.24 | 30.2 | 101. | .656E-02 | .172E+03 | .491E+02 | 0.82 | |
| 9 | 20.32 | 32.4 | 81. | .528E-02 | .139E+03 | .395E+02 | 0.20 | |
| 10 | 38.10 | 37.1 | 57. | .374E-02 | .981E+02 | .280E+02 | 0.13 | |
| 11 | 63.50 | 39.2 | 51. | .332E-02 | .871E+02 | .249E+02 | 0.05 | |
| 12 | 76.20 | 39.4 | 51. | .330E-02 | .865E+02 | .247E+02 | 0.01 | |

Table A.26: .5 in. cylinder with $D=4$ in.; $U = 12.7(m/s)$, $T = 20.8(^{\circ}C)$, $q = 938(W/m^2)$, $i = 42.0(A)$

Case:5twb-10

Date and time of experiment: Nov.3,1992, 04:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 31.3 | | | | | | |
| 2 | 2.54 | 32.9 | 58. | .485E-02 | .992E+02 | .283E+02 | 10.19 | |
| 3 | 6.35 | 32.0 | 69. | .575E-02 | .118E+03 | .335E+02 | 1.48 | |
| 4 | 7.62 | 31.4 | 72. | .603E-02 | .123E+03 | .352E+02 | 1.96 | |
| 5 | 8.89 | 30.7 | 80. | .672E-02 | .137E+03 | .392E+02 | 1.52 | |
| 6 | 10.16 | 30.1 | 86. | .719E-02 | .147E+03 | .420E+02 | 1.96 | |
| 7 | 12.70 | 29.4 | 94. | .785E-02 | .160E+03 | .458E+02 | 3.07 | X_{max} |
| 8 | 15.24 | 29.8 | 87. | .730E-02 | .149E+03 | .426E+02 | 0.98 | |
| 9 | 20.32 | 31.8 | 71. | .592E-02 | .121E+03 | .345E+02 | 0.19 | |
| 10 | 38.10 | 36.6 | 49. | .413E-02 | .845E+02 | .241E+02 | 0.15 | |
| 11 | 63.50 | 38.8 | 43. | .362E-02 | .740E+02 | .211E+02 | 0.07 | |
| 12 | 76.20 | 39.0 | 43. | .358E-02 | .733E+02 | .209E+02 | 0.02 | |

Table A.27: .5 in. cylinder with $D=4$ in.; $U = 9.9(m/s)$, $T = 20.8(^{\circ}C)$,
 $q = 778(W/m^2)$, $i = 38.3(A)$

Case:5twb-8.7

Date and time of experiment: Nov.3,1992, 03:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 31.3 | | | | | | |
| 2 | 2.54 | 32.8 | 53. | .506E-02 | .902E+02 | .258E+02 | 10.57 | |
| 3 | 6.35 | 32.1 | 61. | .589E-02 | .105E+03 | .300E+02 | 1.77 | |
| 4 | 7.62 | 31.6 | 64. | .611E-02 | .109E+03 | .311E+02 | 2.83 | |
| 5 | 8.89 | 30.8 | 72. | .687E-02 | .122E+03 | .349E+02 | 1.42 | |
| 6 | 10.16 | 30.2 | 77. | .740E-02 | .132E+03 | .377E+02 | 2.36 | |
| 7 | 12.70 | 29.5 | 84. | .806E-02 | .144E+03 | .410E+02 | 3.16 | X_{max} |
| 8 | 15.24 | 29.9 | 79. | .758E-02 | .135E+03 | .386E+02 | 1.15 | |
| 9 | 20.32 | 31.8 | 64. | .619E-02 | .110E+03 | .315E+02 | 0.18 | |
| 10 | 38.10 | 36.6 | 45. | .432E-02 | .770E+02 | .220E+02 | 0.16 | |
| 11 | 63.50 | 38.9 | 39. | .377E-02 | .672E+02 | .192E+02 | 0.08 | |
| 12 | 76.20 | 39.1 | 39. | .374E-02 | .667E+02 | .190E+02 | 0.02 | |

Table A.28: .5 in. cylinder with $D=4$ in.; $U = 8.7(m/s)$, $T = 20.7(^{\circ}C)$,
 $q = 716(W/m^2)$, $i = 36.7(A)$

Case: 5twb-7.5a

Date and time of experiment: Nov.3,1992, 03:15

| No. | X(cm) | T(°C) | h | St | Nu _s | Nu _d | cond% | |
|-----|-------|-------|-----|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 31.0 | | | | | | |
| 2 | 2.54 | 32.5 | 47. | .531E-02 | .805E+02 | .230E+02 | 11.32 | |
| 3 | 6.35 | 32.0 | 54. | .612E-02 | .928E+02 | .265E+02 | 2.29 | |
| 4 | 7.62 | 31.5 | 56. | .635E-02 | .963E+02 | .275E+02 | 3.27 | |
| 5 | 8.89 | 30.7 | 63. | .716E-02 | .109E+03 | .310E+02 | 1.50 | |
| 6 | 10.16 | 30.1 | 69. | .774E-02 | .117E+03 | .335E+02 | 2.59 | |
| 7 | 12.70 | 29.4 | 75. | .845E-02 | .128E+03 | .366E+02 | 3.44 | X _{max} |
| 8 | 15.24 | 29.7 | 71. | .800E-02 | .121E+03 | .346E+02 | 1.32 | |
| 9 | 20.32 | 31.4 | 58. | .658E-02 | .997E+02 | .285E+02 | 0.16 | |
| 10 | 38.10 | 36.1 | 40. | .457E-02 | .693E+02 | .198E+02 | 0.17 | |
| 11 | 63.50 | 38.5 | 35. | .396E-02 | .600E+02 | .171E+02 | 0.09 | |
| 12 | 76.20 | 38.6 | 35. | .393E-02 | .596E+02 | .170E+02 | 0.02 | |

Table A.29: .5 in. cylinder with D=4 in.; $U = 7.4(m/s)$, $T = 20.8(^{\circ}C)$,
 $q = 621(W/m^2)$, $i = 34.3(A)$

Case: 5twb-7.5b

Date and time of experiment: Nov.3,1992, 05:20

| No. | X(cm) | T(°C) | h | St | Nu _s | Nu _d | cond% | |
|-----|-------|-------|-----|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 30.7 | | | | | | |
| 2 | 2.54 | 32.3 | 48. | .530E-02 | .822E+02 | .235E+02 | 11.73 | |
| 3 | 6.35 | 31.7 | 56. | .617E-02 | .956E+02 | .273E+02 | 2.19 | |
| 4 | 7.62 | 31.2 | 58. | .642E-02 | .994E+02 | .284E+02 | 2.94 | |
| 5 | 8.89 | 30.5 | 65. | .718E-02 | .111E+03 | .318E+02 | 1.09 | |
| 6 | 10.10 | 29.9 | 71. | .779E-02 | .121E+03 | .345E+02 | 2.76 | |
| 7 | 12.70 | 29.2 | 77. | .847E-02 | .131E+03 | .375E+02 | 3.22 | X _{max} |
| 8 | 15.24 | 29.4 | 73. | .805E-02 | .125E+03 | .356E+02 | 1.41 | |
| 9 | 20.32 | 31.3 | 59. | .655E-02 | .102E+03 | .290E+02 | 0.17 | |
| 10 | 38.10 | 36.1 | 41. | .450E-02 | .697E+02 | .199E+02 | 0.18 | |
| 11 | 63.50 | 38.5 | 35. | .391E-02 | .606E+02 | .173E+02 | 0.09 | |
| 12 | 76.20 | 38.7 | 35. | .387E-02 | .600E+02 | .171E+02 | 0.02 | |

Table A.30: .5 in. cylinder with D=4 in.; $U = 7.5(m/s)$, $T = 20.7(^{\circ}C)$,
 $q = 631(W/m^2)$, $i = 34.4(A)$

Case: 5twb- 06

Date and time of experiment: Nov.3.1992, 04:25

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 30.4 | | | | | | |
| 2 | 2.54 | 31.9 | 42. | .574E-02 | .712E+02 | .203E+02 | 12.69 | |
| 3 | 6.35 | 31.6 | 48. | .660E-02 | .818E+02 | .233E+02 | 2.93 | |
| 4 | 7.62 | 31.1 | 50. | .684E-02 | .848E+02 | .242E+02 | 3.88 | |
| 5 | 8.89 | 30.3 | 56. | .778E-02 | .965E+02 | .275E+02 | 1.55 | |
| 6 | 10.16 | 29.7 | 61. | .846E-02 | .105E+03 | .299E+02 | 3.11 | |
| 7 | 12.70 | 29.0 | 67. | .923E-02 | .114E+03 | .326E+02 | 3.81 | X_{max} |
| 8 | 15.24 | 29.3 | 63. | .873E-02 | .108E+03 | .309E+02 | 1.48 | |
| 9 | 20.32 | 31.0 | 52. | .719E-02 | .891E+02 | .254E+02 | 0.14 | |
| 10 | 38.10 | 35.8 | 36. | .491E-02 | .609E+02 | .174E+02 | 0.20 | |
| 11 | 63.50 | 38.3 | 31. | .423E-02 | .524E+02 | .150E+02 | 0.12 | |
| 12 | 76.20 | 38.4 | 30. | .420E-02 | .521E+02 | .149E+02 | 0.02 | |

Table A.31: .5 in. cylinder with $D=4$ in.; $U = 6.0(m/s)$, $T = 20.5(^{\circ}C)$,
 $q = 544(W/m^2)$, $i = 32.0(A)$

Case: 5twb- 05

Date and time of experiment: Nov.3.1992, 03:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 30.4 | | | | | | |
| 2 | 2.54 | 32.0 | 37. | .607E-02 | .628E+02 | .179E+02 | 13.95 | |
| 3 | 6.35 | 31.7 | 42. | .698E-02 | .722E+02 | .206E+02 | 3.31 | |
| 4 | 7.62 | 31.2 | 44. | .724E-02 | .748E+02 | .213E+02 | 3.97 | |
| 5 | 8.89 | 30.5 | 49. | .815E-02 | .842E+02 | .240E+02 | 1.04 | |
| 6 | 10.16 | 29.9 | 54. | .889E-02 | .919E+02 | .262E+02 | 3.28 | |
| 7 | 12.70 | 29.2 | 58. | .969E-02 | .100E+03 | .286E+02 | 4.01 | X_{max} |
| 8 | 15.24 | 29.4 | 56. | .924E-02 | .955E+02 | .272E+02 | 1.74 | |
| 9 | 20.32 | 31.1 | 46. | .766E-02 | .791E+02 | .226E+02 | 0.13 | |
| 10 | 38.10 | 35.9 | 32. | .526E-02 | .543E+02 | .155E+02 | 0.22 | |
| 11 | 63.50 | 38.4 | 27. | .451E-02 | .466E+02 | .133E+02 | 0.13 | |
| 12 | 76.20 | 38.6 | 27. | .448E-02 | .463E+02 | .132E+02 | 0.02 | |

Table A.32: .5 in. cylinder with $D=4$ in.; $U = 5.0(m/s)$, $T = 20.5(^{\circ}C)$,
 $q = 490(W/m^2)$, $i = 30.4(A)$

**A.a-iii Data and Results for 1" cylinder in Different
Velocities; $S = 0.5''$**

Case: 1twa-30a

Date and time of experiment: Oct.04,1992, 01:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.2 | | | | | | |
| 2 | 2.54 | 35.5 | 135. | .378E-02 | .658E+02 | .132E+03 | 3.80 | |
| 3 | 3.81 | 33.6 | 199. | .559E-02 | .972E+02 | .194E+03 | 17.18 | |
| 4 | 5.08 | 32.9 | 211. | .591E-02 | .103E+03 | .206E+03 | 14.08 | X_{max} |
| 5 | 6.35 | 33.1 | 136. | .550E-02 | .956E+02 | .191E+03 | 9.44 | |
| 6 | 7.62 | 34.1 | 163. | .456E-02 | .794E+02 | .159E+03 | 0.70 | |
| 7 | 8.89 | 35.1 | 141. | .397E-02 | .691E+02 | .138E+03 | 3.38 | |
| 8 | 10.16 | 35.8 | 137. | .385E-02 | .669E+02 | .134E+03 | 0.14 | |
| 9 | 11.43 | 36.6 | 123. | .346E-02 | .603E+02 | .121E+03 | 3.80 | |
| 10 | 12.70 | 37.1 | 121. | .340E-02 | .592E+02 | .118E+03 | 1.69 | |
| 11 | 13.97 | 37.4 | 120. | .336E-02 | .584E+02 | .117E+03 | 0.14 | |
| 12 | 15.24 | 37.8 | 115. | .323E-02 | .561E+02 | .112E+03 | 1.41 | |
| 13 | 17.78 | 38.2 | 114. | .319E-02 | .556E+02 | .111E+03 | 0.66 | |
| 14 | 19.05 | 38.5 | 110. | .308E-02 | .536E+02 | .107E+03 | 0.85 | |
| 15 | 20.32 | 38.7 | 108. | .303E-02 | .527E+02 | .105E+03 | 0.99 | |
| 16 | 22.86 | 38.9 | 107. | .302E-02 | .525E+02 | .105E+03 | 0.14 | |
| 17 | 25.40 | 39.2 | 105. | .296E-02 | .514E+02 | .103E+03 | 0.11 | |
| 18 | 27.94 | 39.4 | 103. | .290E-02 | .504E+02 | .101E+03 | 0.46 | |
| 19 | 30.48 | 39.6 | 103. | .289E-02 | .503E+02 | .101E+03 | 0.01 | |
| 20 | 35.56 | 39.8 | 102. | .286E-02 | .498E+02 | .996E+02 | 0.39 | |
| 21 | 38.10 | 40.0 | 99. | .278E-02 | .484E+02 | .967E+02 | 0.77 | |
| 22 | 40.64 | 40.1 | 99. | .279E-02 | .486E+02 | .972E+02 | 0.02 | |
| 23 | 63.50 | 40.8 | 95. | .267E-02 | .464E+02 | .929E+02 | 0.01 | |
| 24 | 76.20 | 41.1 | 94. | .263E-02 | .457E+02 | .914E+02 | 0.01 | |
| 25 | 88.90 | 41.4 | 92. | .257E-02 | .448E+02 | .895E+02 | 0.05 | |

Table A.33: 1 in. cylinder with $S=.5$ in.; $U = 30.0(m/s)$, $T = 24.4(^{\circ}C)$, $q = 1559(W/m^2)$, $i = 170.0(A)$

Case: Itwa-30b

Date and time of experiment: Oct.04,1992, 03:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.2 | | | | | | |
| 2 | 2.54 | 35.5 | 137. | .386E-02 | .670E+02 | .134E+03 | 3.11 | |
| 3 | 3.81 | 33.5 | 201. | .565E-02 | .979E+02 | .196E+03 | 16.95 | |
| 4 | 5.08 | 32.8 | 213. | .600E-02 | .104E+03 | .208E+03 | 14.41 | X_{max} |
| 5 | 6.35 | 33.1 | 197. | .554E-02 | .960E+02 | .192E+03 | 9.32 | |
| 6 | 7.62 | 34.1 | 162. | .457E-02 | .792E+02 | .158E+03 | 0.14 | |
| 7 | 8.89 | 35.1 | 142. | .401E-02 | .696E+02 | .139E+03 | 3.11 | |
| 8 | 10.16 | 35.8 | 137. | .386E-02 | .669E+02 | .134E+03 | 0.14 | |
| 9 | 11.43 | 36.5 | 124. | .350E-02 | .606E+02 | .121E+03 | 3.67 | |
| 10 | 12.70 | 37.0 | 122. | .344E-02 | .597E+02 | .119E+03 | 1.41 | |
| 11 | 13.97 | 37.4 | 120. | .338E-02 | .586E+02 | .117E+03 | 0.28 | |
| 12 | 15.24 | 37.8 | 115. | .325E-02 | .563E+02 | .113E+03 | 1.47 | |
| 13 | 17.78 | 38.2 | 114. | .322E-02 | .558E+02 | .112E+03 | 0.66 | |
| 14 | 19.05 | 38.5 | 110. | .311E-02 | .538E+02 | .108E+03 | 0.85 | |
| 15 | 20.32 | 38.7 | 108. | .305E-02 | .529E+02 | .106E+03 | 1.08 | |
| 16 | 22.86 | 38.9 | 108. | .304E-02 | .528E+02 | .106E+03 | 0.18 | |
| 17 | 25.40 | 39.1 | 106. | .298E-02 | .517E+02 | .103E+03 | 0.11 | |
| 18 | 27.94 | 39.4 | 104. | .293E-02 | .507E+02 | .101E+03 | 0.39 | |
| 19 | 30.48 | 39.5 | 103. | .291E-02 | .505E+02 | .101E+03 | 0.00 | |
| 20 | 35.56 | 39.7 | 102. | .288E-02 | .499E+02 | .998E+02 | 0.28 | |
| 21 | 38.10 | 40.0 | 100. | .281E-02 | .487E+02 | .973E+02 | 0.64 | |
| 22 | 40.64 | 40.0 | 100. | .281E-02 | .488E+02 | .976E+02 | 0.01 | |
| 23 | 63.50 | 40.7 | 96. | .270E-02 | .469E+02 | .938E+02 | 0.01 | |
| 24 | 76.20 | 40.9 | 95. | .267E-02 | .463E+02 | .925E+02 | 0.02 | |
| 25 | 88.90 | 41.3 | 93. | .261E-02 | .452E+02 | .904E+02 | 0.05 | |

Table A.34: 1 in. cylinder with $S=.5$ in.; $U = 29.9(m/s)$, $T = 24.5(^{\circ}C)$, $q = 1555(W/m^2)$, $i = 170.0(A)$

Case: 1twa-27.5

Date and time of experiment: Oct.04,1992, 01:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.7 | | | | | | |
| 2 | 2.54 | 35.2 | 125. | .381E-02 | .610E+02 | .122E+03 | 5.04 | |
| 3 | 3.81 | 33.3 | 185. | .566E-02 | .906E+02 | .181E+03 | 16.95 | |
| 4 | 5.08 | 32.6 | 199. | .607E-02 | .972E+02 | .194E+03 | 15.12 | X_{max} |
| 5 | 6.35 | 32.8 | 186. | .567E-02 | .907E+02 | .181E+03 | 10.54 | |
| 6 | 7.62 | 33.7 | 152. | .465E-02 | .745E+02 | .149E+03 | 0.61 | |
| 7 | 8.89 | 34.7 | 133. | .405E-02 | .649E+02 | .130E+03 | 3.36 | |
| 8 | 10.16 | 35.4 | 128. | .392E-02 | .628E+02 | .126E+03 | 0.15 | |
| 9 | 11.43 | 36.2 | 115. | .352E-02 | .563E+02 | .113E+03 | 3.97 | |
| 10 | 12.70 | 36.7 | 113. | .346E-02 | .553E+02 | .111E+03 | 1.83 | |
| 11 | 13.97 | 37.1 | 112. | .341E-02 | .546E+02 | .109E+03 | 0.15 | |
| 12 | 15.24 | 37.4 | 107. | .327E-02 | .523E+02 | .105E+03 | 1.53 | |
| 13 | 17.78 | 37.9 | 106. | .323E-02 | .516E+02 | .103E+03 | 0.41 | |
| 14 | 19.05 | 38.1 | 102. | .312E-02 | .500E+02 | .100E+03 | 0.92 | |
| 15 | 20.32 | 38.4 | 101. | .308E-02 | .493E+02 | .986E+02 | 0.87 | |
| 16 | 22.86 | 38.6 | 100. | .307E-02 | .491E+02 | .981E+02 | 0.23 | |
| 17 | 25.40 | 38.9 | 98. | .299E-02 | .479E+02 | .958E+02 | 0.15 | |
| 18 | 27.94 | 39.1 | 96. | .294E-02 | .470E+02 | .939E+02 | 0.42 | |
| 19 | 30.48 | 39.3 | 96. | .292E-02 | .467E+02 | .935E+02 | 0.01 | |
| 20 | 35.56 | 39.5 | 94. | .287E-02 | .460E+02 | .920E+02 | 0.19 | |
| 21 | 38.10 | 39.7 | 92. | .281E-02 | .450E+02 | .901E+02 | 0.57 | |
| 22 | 40.64 | 39.8 | 92. | .282E-02 | .451E+02 | .902E+02 | 0.01 | |
| 23 | 63.50 | 40.5 | 88. | .270E-02 | .432E+02 | .864E+02 | 0.01 | |
| 24 | 76.20 | 40.7 | 87. | .266E-02 | .426E+02 | .851E+02 | 0.02 | |
| 25 | 88.90 | 41.1 | 85. | .260E-02 | .416E+02 | .833E+02 | 0.05 | |

Table A.35: 1 in. cylinder with $S=.5$ in.; $U = 27.6(m/s)$, $T = 24.2(^{\circ}C)$, $q = 1438(W/m^2)$, $i = 163.0(A)$

Case: 1twa-25

Date and time of experiment: Oct.04,1992, 02:15

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.1 | | | | | | |
| 2 | 2.54 | 35.4 | 117. | .397E-02 | .571E+02 | .114E+03 | 4.93 | |
| 3 | 3.81 | 33.5 | 178. | .605E-02 | .870E+02 | .174E+03 | 19.41 | |
| 4 | 5.08 | 32.7 | 189. | .640E-02 | .921E+02 | .184E+03 | 16.23 | X_{max} |
| 5 | 6.35 | 33.0 | 174. | .591E-02 | .850E+02 | .170E+03 | 10.66 | |
| 6 | 7.62 | 33.9 | 143. | .487E-02 | .700E+02 | .140E+03 | 0.95 | |
| 7 | 8.89 | 34.9 | 124. | .423E-02 | .608E+02 | .122E+03 | 3.34 | |
| 8 | 10.16 | 35.7 | 120. | .408E-02 | .587E+02 | .117E+03 | 0.16 | |
| 9 | 11.43 | 36.5 | 107. | .364E-02 | .523E+02 | .105E+03 | 4.45 | |
| 10 | 12.70 | 37.0 | 106. | .359E-02 | .516E+02 | .103E+03 | 1.75 | |
| 11 | 13.97 | 37.4 | 104. | .354E-02 | .508E+02 | .102E+03 | 0.16 | |
| 12 | 15.24 | 37.9 | 100. | .339E-02 | .487E+02 | .974E+02 | 1.54 | |
| 13 | 17.78 | 38.4 | 98. | .332E-02 | .478E+02 | .956E+02 | 0.27 | |
| 14 | 19.05 | 38.6 | 95. | .322E-02 | .463E+02 | .926E+02 | 0.95 | |
| 15 | 20.32 | 38.9 | 93. | .317E-02 | .455E+02 | .911E+02 | 1.06 | |
| 16 | 22.86 | 39.1 | 93. | .315E-02 | .454E+02 | .907E+02 | 0.16 | |
| 17 | 25.40 | 39.4 | 91. | .309E-02 | .444E+02 | .889E+02 | 0.04 | |
| 18 | 27.94 | 39.6 | 89. | .302E-02 | .434E+02 | .869E+02 | 0.56 | |
| 19 | 30.48 | 39.8 | 89. | .301E-02 | .433E+02 | .866E+02 | 0.03 | |
| 20 | 35.56 | 40.0 | 88. | .297E-02 | .428E+02 | .855E+02 | 0.27 | |
| 21 | 38.10 | 40.2 | 86. | .291E-02 | .418E+02 | .836E+02 | 0.64 | |
| 22 | 40.64 | 40.3 | 86. | .291E-02 | .419E+02 | .838E+02 | 0.01 | |
| 23 | 63.50 | 40.9 | 83. | .281E-02 | .403E+02 | .807E+02 | 0.01 | |
| 24 | 76.20 | 41.1 | 82. | .277E-02 | .398E+02 | .797E+02 | 0.01 | |
| 25 | 88.90 | 41.4 | 80. | .272E-02 | .391E+02 | .782E+02 | 0.05 | |

Table A.36: 1 in. cylinder with $S=.5$ in.; $U = 24.8(m/s)$, $T = 24.2(^{\circ}C)$, $q = 13S1(W/m^2)$, $i = 160.0(A)$

Case: ltwa-22.5

Date and time of experiment: Oct.04,1992, 01:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.2 | | | | | | |
| 2 | 2.54 | 34.8 | 105. | .395E-02 | .513E+02 | .103E+03 | 6.34 | |
| 3 | 3.81 | 32.9 | 161. | .607E-02 | .789E+02 | .158E+03 | 19.39 | |
| 4 | 5.08 | 32.1 | 173. | .652E-02 | .847E+02 | .169E+03 | 17.22 | X_{max} |
| 5 | 6.35 | 32.3 | 162. | .610E-02 | .792E+02 | .158E+03 | 11.96 | |
| 6 | 7.62 | 33.2 | 133. | .501E-02 | .651E+02 | .130E+03 | 1.27 | |
| 7 | 8.89 | 34.1 | 116. | .437E-02 | .568E+02 | .114E+03 | 2.90 | |
| 8 | 10.16 | 34.8 | 112. | .423E-02 | .549E+02 | .110E+03 | 0.91 | |
| 9 | 11.43 | 35.6 | 99. | .371E-02 | .481E+02 | .963E+02 | 5.07 | |
| 10 | 12.70 | 36.1 | 97. | .366E-02 | .476E+02 | .952E+02 | 1.99 | |
| 11 | 13.97 | 36.6 | 96. | .360E-02 | .468E+02 | .936E+02 | 0.36 | |
| 12 | 15.24 | 36.9 | 92. | .344E-02 | .447E+02 | .895E+02 | 1.81 | |
| 13 | 17.78 | 37.4 | 90. | .340E-02 | .441E+02 | .882E+02 | 0.36 | |
| 14 | 19.05 | 37.7 | 87. | .328E-02 | .426E+02 | .852E+02 | 1.09 | |
| 15 | 20.32 | 37.9 | 86. | .324E-02 | .420E+02 | .840E+02 | 0.97 | |
| 16 | 22.86 | 38.2 | 85. | .321E-02 | .417E+02 | .833E+02 | 0.05 | |
| 17 | 25.40 | 38.4 | 84. | .315E-02 | .409E+02 | .818E+02 | 0.00 | |
| 18 | 27.94 | 38.7 | 82. | .307E-02 | .399E+02 | .798E+02 | 0.59 | |
| 19 | 30.48 | 38.8 | 81. | .306E-02 | .397E+02 | .794E+02 | 0.11 | |
| 20 | 35.56 | 39.1 | 81. | .303E-02 | .393E+02 | .786E+02 | 0.32 | |
| 21 | 38.10 | 39.3 | 79. | .296E-02 | .384E+02 | .768E+02 | 0.68 | |
| 22 | 40.64 | 39.3 | 79. | .297E-02 | .385E+02 | .770E+02 | 0.01 | |
| 23 | 63.50 | 39.9 | 76. | .285E-02 | .371E+02 | .741E+02 | 0.01 | |
| 24 | 76.20 | 40.2 | 75. | .281E-02 | .365E+02 | .729E+02 | 0.01 | |
| 25 | 88.90 | 40.5 | 73. | .275E-02 | .358E+02 | .715E+02 | 0.06 | |

Table A.37: 1 in. cylinder with $S=0.5$ in.; $U = 22.4(m/s)$, $T = 24.0(^{\circ}C)$, $q = 1212(W/m^2)$, $i = 150.0(A)$

Case: 1twa-20

Date and time of experiment: Oct.04,1992, 02:30

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 37.1 | | | | | | |
| 2 | 2.54 | 35.6 | 98. | .412E-02 | .478E+02 | .956E+02 | 7.60 | |
| 3 | 3.81 | 33.6 | 155. | .651E-02 | .755E+02 | .151E+03 | 20.82 | |
| 4 | 5.08 | 32.8 | 166. | .698E-02 | .809E+02 | .162E+03 | 18.28 | X _{max} |
| 5 | 6.35 | 33.0 | 155. | .652E-02 | .756E+02 | .151E+03 | 12.85 | |
| 6 | 7.62 | 33.9 | 127. | .534E-02 | .619E+02 | .124E+03 | 1.81 | |
| 7 | 8.89 | 34.9 | 109. | .460E-02 | .533E+02 | .107E+03 | 3.26 | |
| 8 | 10.16 | 35.7 | 105. | .442E-02 | .513E+02 | .103E+03 | 0.18 | |
| 9 | 11.43 | 36.6 | 94. | .395E-02 | .458E+02 | .916E+02 | 4.16 | |
| 10 | 12.70 | 37.1 | 91. | .383E-02 | .444E+02 | .889E+02 | 2.53 | |
| 11 | 13.97 | 37.6 | 90. | .379E-02 | .440E+02 | .879E+02 | 0.18 | |
| 12 | 15.24 | 38.1 | 86. | .361E-02 | .419E+02 | .838E+02 | 1.69 | |
| 13 | 17.78 | 38.7 | 83. | .351E-02 | .407E+02 | .815E+02 | 0.12 | |
| 14 | 19.05 | 39.0 | 81. | .340E-02 | .395E+02 | .789E+02 | 1.27 | |
| 15 | 20.32 | 39.2 | 80. | .336E-02 | .390E+02 | .780E+02 | 0.91 | |
| 16 | 22.86 | 39.5 | 79. | .332E-02 | .386E+02 | .771E+02 | 0.00 | |
| 17 | 25.40 | 39.8 | 77. | .326E-02 | .378E+02 | .755E+02 | 0.09 | |
| 18 | 27.94 | 40.1 | 75. | .318E-02 | .369E+02 | .737E+02 | 0.68 | |
| 19 | 30.48 | 40.3 | 75. | .317E-02 | .368E+02 | .736E+02 | 0.02 | |
| 20 | 35.56 | 40.6 | 74. | .312E-02 | .362E+02 | .725E+02 | 0.26 | |
| 21 | 38.10 | 40.8 | 72. | .305E-02 | .354E+02 | .708E+02 | 0.72 | |
| 22 | 40.64 | 40.9 | 73. | .306E-02 | .355E+02 | .710E+02 | 0.01 | |
| 23 | 63.50 | 41.5 | 70. | .294E-02 | .341E+02 | .682E+02 | 0.03 | |
| 24 | 76.20 | 41.7 | 69. | .291E-02 | .338E+02 | .675E+02 | 0.01 | |
| 25 | 88.90 | 41.9 | 68. | .288E-02 | .334E+02 | .667E+02 | 0.04 | |

Table A.38: 1 in. cylinder with S=.5 in.; $U = 20.0(m/s)$, $T = 24.2(^{\circ}C)$, $q = 1213(W/m^2)$, $i = 150.0(A)$

Case: 1twa-17.5

Date and time of experiment: Oct.04,1992, 02:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.0 | | | | | | |
| 2 | 2.54 | 35.5 | 87. | .421E-02 | .427E+02 | .854E+02 | 9.23 | |
| 3 | 3.81 | 33.5 | 142. | .684E-02 | .694E+02 | .139E+03 | 22.07 | |
| 4 | 5.08 | 32.7 | 153. | .737E-02 | .747E+02 | .149E+03 | 19.66 | X_{max} |
| 5 | 6.35 | 32.8 | 144. | .691E-02 | .702E+02 | .140E+03 | 14.04 | |
| 6 | 7.62 | 33.6 | 118. | .568E-02 | .576E+02 | .115E+03 | 2.61 | |
| 7 | 8.89 | 34.6 | 101. | .488E-02 | .495E+02 | .990E+02 | 3.01 | |
| 8 | 10.16 | 35.4 | 97. | .468E-02 | .475E+02 | .949E+02 | 0.20 | |
| 9 | 11.43 | 36.2 | 86. | .416E-02 | .422E+02 | .844E+02 | 4.41 | |
| 10 | 12.70 | 36.8 | 84. | .404E-02 | .410E+02 | .819E+02 | 2.61 | |
| 11 | 13.97 | 37.3 | 83. | .399E-02 | .405E+02 | .810E+02 | 0.20 | |
| 12 | 15.24 | 37.8 | 79. | .379E-02 | .385E+02 | .770E+02 | 1.81 | |
| 13 | 17.78 | 38.4 | 76. | .368E-02 | .373E+02 | .747E+02 | 0.20 | |
| 14 | 19.05 | 38.7 | 74. | .356E-02 | .361E+02 | .722E+02 | 1.40 | |
| 15 | 20.32 | 39.0 | 73. | .351E-02 | .356E+02 | .713E+02 | 1.07 | |
| 16 | 22.86 | 39.3 | 72. | .348E-02 | .353E+02 | .705E+02 | 0.00 | |
| 17 | 25.40 | 39.6 | 71. | .340E-02 | .345E+02 | .690E+02 | 0.05 | |
| 18 | 27.94 | 39.9 | 69. | .331E-02 | .336E+02 | .672E+02 | 0.70 | |
| 19 | 30.48 | 40.1 | 69. | .330E-02 | .335E+02 | .670E+02 | 0.05 | |
| 20 | 35.56 | 40.4 | 67. | .325E-02 | .330E+02 | .659E+02 | 0.28 | |
| 21 | 38.10 | 40.6 | 66. | .317E-02 | .322E+02 | .643E+02 | 0.70 | |
| 22 | 40.64 | 40.7 | 66. | .317E-02 | .322E+02 | .644E+02 | 0.02 | |
| 23 | 63.50 | 41.4 | 63. | .305E-02 | .309E+02 | .618E+02 | 0.04 | |
| 24 | 76.20 | 41.5 | 63. | .303E-02 | .307E+02 | .615E+02 | 0.01 | |
| 25 | 88.90 | 41.7 | 62. | .300E-02 | .304E+02 | .608E+02 | 0.03 | |

Table A.39: 1 in. cylinder with $S=.5$ in.; $U = 17.5(m/s)$, $T = 24.1(^{\circ}C)$, $q = 1095(W/m^2)$, $i = 143.0(A)$

Case: Itwa-15a

Date and time of experiment: Oct.04,1992, 00:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.5 | | | | | | |
| 2 | 2.54 | 36.2 | 74. | .415E-02 | .361E+02 | .722E+02 | 13.92 | |
| 3 | 3.81 | 34.2 | 122. | .684E-02 | .595E+02 | .119E+03 | 19.11 | |
| 4 | 5.08 | 33.2 | 139. | .783E-02 | .681E+02 | .136E+03 | 22.43 | X_{max} |
| 5 | 6.35 | 33.2 | 132. | .742E-02 | .645E+02 | .129E+03 | 16.41 | |
| 6 | 7.62 | 34.0 | 108. | .609E-02 | .530E+02 | .106E+03 | 3.95 | |
| 7 | 8.89 | 35.1 | 93. | .520E-02 | .453E+02 | .905E+02 | 2.28 | |
| 8 | 10.16 | 35.9 | 88. | .497E-02 | .432E+02 | .864E+02 | 0.83 | |
| 9 | 11.43 | 36.9 | 78. | .435E-02 | .379E+02 | .757E+02 | 4.78 | |
| 10 | 12.70 | 37.6 | 75. | .420E-02 | .365E+02 | .731E+02 | 3.12 | |
| 11 | 13.97 | 38.2 | 74. | .415E-02 | .361E+02 | .721E+02 | 0.42 | |
| 12 | 15.24 | 38.7 | 70. | .392E-02 | .341E+02 | .682E+02 | 2.28 | |
| 13 | 17.78 | 39.4 | 68. | .381E-02 | .331E+02 | .663E+02 | 0.21 | |
| 14 | 19.05 | 39.8 | 65. | .367E-02 | .319E+02 | .639E+02 | 1.66 | |
| 15 | 20.32 | 40.1 | 65. | .364E-02 | .317E+02 | .634E+02 | 0.69 | |
| 16 | 22.86 | 40.6 | 63. | .355E-02 | .309E+02 | .618E+02 | 0.42 | |
| 17 | 25.40 | 40.9 | 62. | .348E-02 | .303E+02 | .606E+02 | 0.16 | |
| 18 | 27.94 | 41.3 | 60. | .339E-02 | .295E+02 | .590E+02 | 0.73 | |
| 19 | 30.48 | 41.5 | 60. | .337E-02 | .293E+02 | .587E+02 | 0.07 | |
| 20 | 35.56 | 41.9 | 59. | .333E-02 | .290E+02 | .579E+02 | 0.73 | |
| 21 | 38.10 | 42.3 | 57. | .319E-02 | .277E+02 | .555E+02 | 1.40 | |
| 22 | 40.64 | 42.4 | 57. | .321E-02 | .279E+02 | .558E+02 | 0.05 | |
| 23 | 63.50 | 43.1 | 55. | .309E-02 | .268E+02 | .537E+02 | 0.04 | |
| 24 | 76.20 | 43.3 | 54. | .306E-02 | .266E+02 | .532E+02 | 0.02 | |
| 25 | 88.90 | 43.4 | 54. | .305E-02 | .265E+02 | .531E+02 | 0.01 | |

Table A.40: 1 in. cylinder with $S=.5$ in.; $U = 15.0(m/s)$, $T = 23.9(^{\circ}C)$, $q = 1058(W/m^2)$, $i = 140.0(A)$

Case: 1twa-15b

Date and time of experiment: Oct.04,1992, 03:00

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 37.6 | | | | | | |
| 2 | 2.54 | 36.3 | 73. | .408E-02 | .357E+02 | .714E+02 | 14.30 | |
| 3 | 3.81 | 34.3 | 121. | .676E-02 | .592E+02 | .118E+03 | 19.68 | |
| 4 | 5.08 | 33.3 | 137. | .762E-02 | .668E+02 | .134E+03 | 21.96 | X _{max} |
| 5 | 6.35 | 33.4 | 130. | .724E-02 | .634E+02 | .127E+03 | 16.37 | |
| 6 | 7.62 | 34.2 | 106. | .593E-02 | .519E+02 | .104E+03 | 3.73 | |
| 7 | 8.89 | 35.2 | 91. | .507E-02 | .444E+02 | .888E+02 | 2.49 | |
| 8 | 10.16 | 36.1 | 87. | .484E-02 | .424E+02 | .847E+02 | 0.41 | |
| 9 | 11.43 | 37.0 | 77. | .429E-02 | .375E+02 | .751E+02 | 4.35 | |
| 10 | 12.70 | 37.8 | 74. | .412E-02 | .361E+02 | .722E+02 | 3.11 | |
| 11 | 13.97 | 38.3 | 73. | .407E-02 | .357E+02 | .713E+02 | 0.41 | |
| 12 | 15.24 | 38.9 | 69. | .386E-02 | .338E+02 | .677E+02 | 2.00 | |
| 13 | 17.78 | 39.6 | 67. | .372E-02 | .325E+02 | .651E+02 | 0.76 | |
| 14 | 19.05 | 40.0 | 65. | .361E-02 | .316E+02 | .631E+02 | 1.66 | |
| 15 | 20.32 | 40.2 | 64. | .358E-02 | .314E+02 | .627E+02 | 0.69 | |
| 16 | 22.86 | 40.7 | 63. | .351E-02 | .307E+02 | .614E+02 | 0.26 | |
| 17 | 25.40 | 41.0 | 62. | .344E-02 | .301E+02 | .602E+02 | 0.10 | |
| 18 | 27.94 | 41.4 | 60. | .335E-02 | .293E+02 | .586E+02 | 0.73 | |
| 19 | 30.48 | 41.6 | 60. | .333E-02 | .292E+02 | .584E+02 | 0.03 | |
| 20 | 35.56 | 42.0 | 59. | .327E-02 | .286E+02 | .572E+02 | 0.21 | |
| 21 | 38.10 | 42.3 | 57. | .320E-02 | .280E+02 | .560E+02 | 0.57 | |
| 22 | 40.64 | 42.4 | 57. | .319E-02 | .279E+02 | .558E+02 | 0.06 | |
| 23 | 63.50 | 43.2 | 55. | .305E-02 | .267E+02 | .534E+02 | 0.05 | |
| 24 | 76.20 | 43.4 | 54. | .303E-02 | .265E+02 | .530E+02 | 0.01 | |
| 25 | 88.90 | 43.5 | 54. | .301E-02 | .264E+02 | .528E+02 | 0.02 | |

Table A.41: 1 in. cylinder with S=.5 in.; $U = 15.1(m/s)$, $T = 23.8(^{\circ}C)$, $q = 1060(W/m^2)$, $i = 140.0(A)$

Case: 1twa-12.5

Date and time of experiment: Oct.04,1992, 04:00

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 38.1 | | | | | | |
| 2 | 2.54 | 36.7 | 59. | .399E-02 | .287E+02 | .573E+02 | 16.87 | |
| 3 | 3.81 | 34.6 | 103. | .699E-02 | .503E+02 | .101E+03 | 21.94 | |
| 4 | 5.08 | 33.4 | 118. | .803E-02 | .578E+02 | .116E+03 | 24.35 | |
| 5 | 6.35 | 33.2 | 118. | .805E-02 | .579E+02 | .116E+03 | 21.94 | X _{max} |
| 6 | 7.62 | 33.9 | 96. | .649E-02 | .467E+02 | .933E+02 | 5.79 | |
| 7 | 8.89 | 34.9 | 81. | .551E-02 | .396E+02 | .793E+02 | 1.69 | |
| 8 | 10.16 | 35.7 | 76. | .519E-02 | .373E+02 | .747E+02 | 0.00 | |
| 9 | 11.43 | 36.6 | 68. | .465E-02 | .334E+02 | .669E+02 | 3.86 | |
| 10 | 12.70 | 37.3 | 65. | .445E-02 | .320E+02 | .639E+02 | 2.89 | |
| 11 | 13.97 | 37.9 | 64. | .434E-02 | .312E+02 | .624E+02 | 0.96 | |
| 12 | 15.24 | 38.5 | 61. | .413E-02 | .297E+02 | .594E+02 | 2.01 | |
| 13 | 17.78 | 39.4 | 58. | .394E-02 | .283E+02 | .566E+02 | 1.04 | |
| 14 | 19.05 | 39.7 | 56. | .381E-02 | .274E+02 | .548E+02 | 1.93 | |
| 15 | 20.32 | 40.0 | 56. | .378E-02 | .271E+02 | .543E+02 | 1.12 | |
| 16 | 22.86 | 40.5 | 55. | .371E-02 | .267E+02 | .533E+02 | 0.24 | |
| 17 | 25.40 | 40.9 | 53. | .363E-02 | .261E+02 | .522E+02 | 0.06 | |
| 18 | 27.94 | 41.3 | 52. | .351E-02 | .253E+02 | .505E+02 | 0.96 | |
| 19 | 30.48 | 41.5 | 51. | .350E-02 | .251E+02 | .503E+02 | 0.16 | |
| 20 | 35.56 | 41.9 | 51. | .344E-02 | .247E+02 | .495E+02 | 0.32 | |
| 21 | 38.10 | 42.1 | 49. | .335E-02 | .241E+02 | .482E+02 | 0.84 | |
| 22 | 40.64 | 42.3 | 49. | .335E-02 | .241E+02 | .482E+02 | 0.05 | |
| 23 | 63.50 | 43.1 | 47. | .321E-02 | .231E+02 | .461E+02 | 0.07 | |
| 24 | 76.20 | 43.1 | 47. | .320E-02 | .230E+02 | .460E+02 | 0.02 | |
| 25 | 88.90 | 43.1 | 47. | .321E-02 | .230E+02 | .461E+02 | 0.00 | |

Table A.42: 1 in. cylinder with S=.5 in.; $U = 12.4(m/s)$, $T = 23.8(^{\circ}C)$, $q = 911(W/m^2)$, $i = 130.0(A)$

Case: ltwa-10

Date and time of experiment: Oct.04,1992, 04:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.2 | | | | | | |
| 2 | 2.54 | 35.1 | 44. | .370E-02 | .217E+02 | .434E+02 | 22.61 | |
| 3 | 3.81 | 33.3 | 81. | .674E-02 | .395E+02 | .789E+02 | 18.56 | |
| 4 | 5.08 | 32.0 | 101. | .846E-02 | .496E+02 | .991E+02 | 29.35 | |
| 5 | 6.35 | 31.6 | 108. | .898E-02 | .526E+02 | .105E+03 | 31.04 | X_{max} |
| 6 | 7.62 | 32.2 | 82. | .683E-02 | .400E+02 | .800E+02 | 6.41 | |
| 7 | 8.89 | 32.9 | 70. | .587E-02 | .344E+02 | .687E+02 | 0.67 | |
| 8 | 10.16 | 33.6 | 67. | .558E-02 | .327E+02 | .653E+02 | 1.69 | |
| 9 | 11.43 | 34.4 | 58. | .485E-02 | .284E+02 | .568E+02 | 4.72 | |
| 10 | 12.70 | 35.0 | 56. | .463E-02 | .271E+02 | .543E+02 | 3.71 | |
| 11 | 13.97 | 35.5 | 55. | .460E-02 | .270E+02 | .539E+02 | 0.00 | |
| 12 | 15.24 | 36.0 | 52. | .430E-02 | .252E+02 | .504E+02 | 2.59 | |
| 13 | 17.78 | 36.8 | 49. | .410E-02 | .240E+02 | .480E+02 | 1.24 | |
| 14 | 19.05 | 37.1 | 47. | .396E-02 | .232E+02 | .464E+02 | 2.02 | |
| 15 | 20.32 | 37.4 | 47. | .389E-02 | .228E+02 | .456E+02 | 1.69 | |
| 16 | 22.86 | 37.8 | 46. | .383E-02 | .224E+02 | .449E+02 | 0.34 | |
| 17 | 25.40 | 38.2 | 45. | .374E-02 | .219E+02 | .438E+02 | 0.17 | |
| 18 | 27.94 | 38.5 | 43. | .362E-02 | .212E+02 | .423E+02 | 1.18 | |
| 19 | 30.48 | 38.8 | 43. | .360E-02 | .211E+02 | .422E+02 | 0.14 | |
| 20 | 35.56 | 39.1 | 42. | .353E-02 | .207E+02 | .413E+02 | 0.25 | |
| 21 | 38.10 | 39.4 | 41. | .344E-02 | .201E+02 | .403E+02 | 0.84 | |
| 22 | 40.64 | 39.5 | 41. | .344E-02 | .201E+02 | .403E+02 | 0.07 | |
| 23 | 63.50 | 40.3 | 39. | .328E-02 | .192E+02 | .384E+02 | 0.09 | |
| 24 | 76.20 | 40.3 | 39. | .326E-02 | .191E+02 | .382E+02 | 0.06 | |
| 25 | 88.90 | 40.2 | 39. | .329E-02 | .193E+02 | .385E+02 | 0.04 | |

Table A.43: 1 in. cylinder with $S=.5$ in.; $U = 10.1(m/s)$, $T = 23.7(^{\circ}C)$,
 $q = 651(W/m^2)$, $i = 110.0(A)$

Case: 1twa-8.7

Date and time of experiment: Oct.04,1992, 04:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 38.7 | | | | | | |
| 2 | 2.54 | 37.8 | 39. | .377E-02 | .190E+02 | .381E+02 | 28.58 | |
| 3 | 3.81 | 35.8 | 71. | .686E-02 | .346E+02 | .693E+02 | 12.17 | |
| 4 | 5.08 | 34.3 | 94. | .914E-02 | .461E+02 | .922E+02 | 30.84 | |
| 5 | 6.35 | 33.9 | 96. | .927E-02 | .468E+02 | .935E+02 | 27.45 | X_{max} |
| 6 | 7.62 | 34.4 | 79. | .764E-02 | .385E+02 | .771E+02 | 10.47 | |
| 7 | 8.89 | 35.3 | 66. | .636E-02 | .321E+02 | .642E+02 | 0.28 | |
| 8 | 10.16 | 36.2 | 62. | .596E-02 | .301E+02 | .601E+02 | 0.57 | |
| 9 | 11.43 | 37.1 | 55. | .535E-02 | .279E+02 | .540E+02 | 3.11 | |
| 10 | 12.70 | 38.0 | 52. | .504E-02 | .254E+02 | .508E+02 | 3.40 | |
| 11 | 13.97 | 38.6 | 51. | .496E-02 | .250E+02 | .501E+02 | 0.28 | |
| 12 | 15.24 | 39.3 | 48. | .465E-02 | .235E+02 | .469E+02 | 2.36 | |
| 13 | 17.78 | 40.4 | 45. | .436E-02 | .220E+02 | .440E+02 | 1.98 | |
| 14 | 19.05 | 40.9 | 43. | .420E-02 | .212E+02 | .424E+02 | 3.11 | |
| 15 | 20.32 | 41.2 | 43. | .421E-02 | .212E+02 | .425E+02 | 0.94 | |
| 16 | 22.86 | 41.8 | 42. | .409E-02 | .206E+02 | .413E+02 | 0.64 | |
| 17 | 25.40 | 42.3 | 41. | .399E-02 | .201E+02 | .403E+02 | 0.35 | |
| 18 | 27.94 | 42.7 | 40. | .388E-02 | .196E+02 | .391E+02 | 0.92 | |
| 19 | 30.48 | 43.1 | 40. | .384E-02 | .194E+02 | .388E+02 | 0.24 | |
| 20 | 35.56 | 43.6 | 39. | .376E-02 | .190E+02 | .379E+02 | 0.14 | |
| 21 | 38.10 | 43.9 | 38. | .367E-02 | .185E+02 | .371E+02 | 0.71 | |
| 22 | 40.64 | 44.1 | 38. | .366E-02 | .185E+02 | .369E+02 | 0.11 | |
| 23 | 63.50 | 45.1 | 36. | .349E-02 | .176E+02 | .352E+02 | 0.10 | |
| 24 | 76.20 | 45.2 | 36. | .347E-02 | .175E+02 | .351E+02 | 0.05 | |
| 25 | 88.90 | 45.1 | 36. | .349E-02 | .176E+02 | .352E+02 | 0.03 | |

Table A.44: 1 in. cylinder with $S=0.5$ in.; $U = 8.7(m/s)$, $T = 23.6(^{\circ}C)$, $q = 776(W/m^2)$, $i = 120.0(A)$

Case: 1twa-7.5a

Date and time of experiment: Oct.04,1992, 03:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 40.9 | | | | | | |
| 2 | 2.54 | 40.1 | 31. | .351E-02 | .153E+02 | .305E+02 | 35.36 | |
| 3 | 3.81 | 38.1 | 57. | .639E-02 | .278E+02 | .556E+02 | 3.01 | |
| 4 | 5.08 | 36.1 | 86. | .970E-02 | .422E+02 | .843E+02 | 35.08 | |
| 5 | 6.35 | 35.4 | 89. | .101E-01 | .437E+02 | .874E+02 | 32.34 | X_{max} |
| 6 | 7.62 | 35.9 | 73. | .821E-02 | .357E+02 | .714E+02 | 12.61 | |
| 7 | 8.89 | 36.8 | 61. | .687E-02 | .299E+02 | .597E+02 | 1.37 | |
| 8 | 10.16 | 37.8 | 57. | .637E-02 | .277E+02 | .554E+02 | 1.10 | |
| 9 | 11.43 | 38.9 | 51. | .571E-02 | .248E+02 | .497E+02 | 2.74 | |
| 10 | 12.70 | 39.8 | 47. | .533E-02 | .232E+02 | .464E+02 | 3.56 | |
| 11 | 13.97 | 40.6 | 47. | .526E-02 | .229E+02 | .457E+02 | 0.27 | |
| 12 | 15.24 | 41.4 | 44. | .491E-02 | .214E+02 | .427E+02 | 2.38 | |
| 13 | 17.78 | 42.8 | 41. | .457E-02 | .199E+02 | .398E+02 | 2.38 | |
| 14 | 19.05 | 43.3 | 39. | .438E-02 | .190E+02 | .381E+02 | 3.84 | |
| 15 | 20.32 | 43.7 | 40. | .444E-02 | .193E+02 | .386E+02 | 0.55 | |
| 16 | 22.86 | 44.4 | 38. | .427E-02 | .186E+02 | .371E+02 | 0.82 | |
| 17 | 25.40 | 45.1 | 37. | .417E-02 | .181E+02 | .363E+02 | 0.27 | |
| 18 | 27.94 | 45.6 | 36. | .402E-02 | .175E+02 | .349E+02 | 1.37 | |
| 19 | 30.48 | 46.0 | 36. | .399E-02 | .174E+02 | .347E+02 | 0.27 | |
| 20 | 35.56 | 46.7 | 35. | .389E-02 | .169E+02 | .339E+02 | 0.05 | |
| 21 | 38.10 | 47.0 | 34. | .381E-02 | .166E+02 | .332E+02 | 0.69 | |
| 22 | 40.64 | 47.2 | 34. | .380E-02 | .165E+02 | .330E+02 | 0.12 | |
| 23 | 63.50 | 48.5 | 32. | .360E-02 | .156E+02 | .313E+02 | 0.13 | |
| 24 | 76.20 | 48.6 | 32. | .359E-02 | .156E+02 | .312E+02 | 0.08 | |
| 25 | 88.90 | 48.3 | 32. | .364E-02 | .158E+02 | .316E+02 | 0.07 | |

Table A.45: 1 in. cylinder with $S=.5$ in.; $U = 7.5(m/s)$, $T = 23.5(^{\circ}C)$,
 $q = 801(W/m^2)$, $i = 120.0(A)$

Case: 1twa-7.5b

Date and time of experiment: Oct.04,1992, 05:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.0 | | | | | | |
| 2 | 2.54 | 34.3 | 33. | .373E-02 | .162E+02 | .324E+02 | 31.77 | |
| 3 | 3.81 | 32.9 | 62. | .698E-02 | .303E+02 | .607E+02 | 10.59 | |
| 4 | 5.08 | 31.6 | 87. | .973E-02 | .423E+02 | .846E+02 | 34.62 | |
| 5 | 6.35 | 31.3 | 87. | .978E-02 | .425E+02 | .851E+02 | 29.33 | X_{max} |
| 6 | 7.62 | 31.6 | 72. | .813E-02 | .354E+02 | .707E+02 | 12.22 | |
| 7 | 8.89 | 32.3 | 60. | .678E-02 | .295E+02 | .589E+02 | 0.81 | |
| 8 | 10.16 | 32.9 | 57. | .636E-02 | .277E+02 | .553E+02 | 1.63 | |
| 9 | 11.43 | 33.6 | 50. | .562E-02 | .244E+02 | .486E+02 | 3.67 | |
| 10 | 12.70 | 34.3 | 47. | .532E-02 | .231E+02 | .463E+02 | 3.26 | |
| 11 | 13.97 | 34.8 | 46. | .520E-02 | .226E+02 | .452E+02 | 0.81 | |
| 12 | 15.24 | 35.3 | 44. | .493E-02 | .214E+02 | .429E+02 | 1.77 | |
| 13 | 17.78 | 36.2 | 40. | .455E-02 | .198E+02 | .395E+02 | 2.58 | |
| 14 | 19.05 | 36.6 | 39. | .439E-02 | .191E+02 | .382E+02 | 3.26 | |
| 15 | 20.32 | 36.9 | 39. | .440E-02 | .192E+02 | .383E+02 | 0.95 | |
| 16 | 22.86 | 37.4 | 38. | .425E-02 | .185E+02 | .370E+02 | 0.92 | |
| 17 | 25.40 | 37.8 | 37. | .417E-02 | .181E+02 | .362E+02 | 0.20 | |
| 18 | 27.94 | 38.1 | 36. | .401E-02 | .175E+02 | .349E+02 | 1.32 | |
| 19 | 30.48 | 38.4 | 36. | .399E-02 | .174E+02 | .347E+02 | 0.27 | |
| 20 | 35.56 | 38.8 | 35. | .390E-02 | .169E+02 | .339E+02 | 0.07 | |
| 21 | 38.10 | 39.0 | 34. | .382E-02 | .166E+02 | .332E+02 | 0.51 | |
| 22 | 40.64 | 39.2 | 34. | .379E-02 | .165E+02 | .330E+02 | 0.15 | |
| 23 | 63.50 | 40.1 | 32. | .360E-02 | .156E+02 | .313E+02 | 0.13 | |
| 24 | 76.20 | 40.1 | 32. | .359E-02 | .156E+02 | .312E+02 | 0.11 | |
| 25 | 88.90 | 39.9 | 32. | .364E-02 | .158E+02 | .316E+02 | 0.09 | |

Table A.46: 1 in. cylinder with $S=.5$ in.; $U = 7.5(m/s)$, $T = 23.2(^{\circ}C)$, $q = 539(W/m^2)$, $i = 100.0(A)$

Case: 1twa-06

Date and time of experiment: Oct.04,1992, 04:30

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 38.1 | | | | | | |
| 2 | 2.54 | 37.2 | 25. | .334E-02 | .120E+02 | .240E+02 | 36.72 | |
| 3 | 3.81 | 35.4 | 45. | .606E-02 | .218E+02 | .436E+02 | 0.00 | |
| 4 | 5.08 | 33.6 | 74. | .101E-01 | .363E+02 | .726E+02 | 42.03 | |
| 5 | 6.35 | 32.8 | 79. | .108E-01 | .388E+02 | .775E+02 | 40.40 | X_{max} |
| 6 | 7.62 | 33.1 | 64. | .876E-02 | .315E+02 | .630E+02 | 16.73 | |
| 7 | 8.89 | 33.7 | 54. | .735E-02 | .264E+02 | .529E+02 | 4.49 | |
| 8 | 10.16 | 34.4 | 50. | .678E-02 | .244E+02 | .487E+02 | 3.26 | |
| 9 | 11.43 | 35.3 | 44. | .593E-02 | .213E+02 | .427E+02 | 2.86 | |
| 10 | 12.70 | 36.0 | 41. | .553E-02 | .199E+02 | .398E+02 | 3.67 | |
| 11 | 13.97 | 36.7 | 40. | .548E-02 | .197E+02 | .394E+02 | 0.41 | |
| 12 | 15.24 | 37.4 | 37. | .505E-02 | .181E+02 | .363E+02 | 2.86 | |
| 13 | 17.78 | 38.5 | 34. | .468E-02 | .168E+02 | .336E+02 | 2.58 | |
| 14 | 19.05 | 39.0 | 33. | .445E-02 | .160E+02 | .320E+02 | 4.49 | |
| 15 | 20.32 | 39.4 | 33. | .451E-02 | .162E+02 | .324E+02 | 0.82 | |
| 16 | 22.86 | 40.1 | 32. | .430E-02 | .155E+02 | .309E+02 | 1.43 | |
| 17 | 25.40 | 40.6 | 31. | .421E-02 | .152E+02 | .303E+02 | 0.31 | |
| 18 | 27.94 | 41.1 | 30. | .404E-02 | .145E+02 | .290E+02 | 1.63 | |
| 19 | 30.48 | 41.5 | 30. | .401E-02 | .144E+02 | .288E+02 | 0.37 | |
| 20 | 35.56 | 42.1 | 29. | .390E-02 | .140E+02 | .280E+02 | 0.03 | |
| 21 | 38.10 | 42.4 | 28. | .382E-02 | .137E+02 | .274E+02 | 0.61 | |
| 22 | 40.64 | 42.6 | 28. | .379E-02 | .136E+02 | .272E+02 | 0.20 | |
| 23 | 63.50 | 43.8 | 26. | .357E-02 | .128E+02 | .257E+02 | 0.17 | |
| 24 | 76.20 | 43.8 | 26. | .356E-02 | .128E+02 | .256E+02 | 0.22 | |
| 25 | 88.90 | 43.3 | 27. | .366E-02 | .132E+02 | .263E+02 | 0.20 | |

Table A.47: 1 in. cylinder with $S=5$ in.; $U = 6.2(m/s)$, $T = 23.3(^{\circ}C)$,
 $q = 538(W/m^2)$, $i = 100.0(A)$

Case: 1twa-05

Date and time of experiment: Oct.04,1992, 05:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.9 | | | | | | |
| 2 | 2.54 | 35.5 | 20. | .331E-02 | .958E+01 | .192E+02 | 44.19 | |
| 3 | 3.81 | 34.1 | 33. | .562E-02 | .163E+02 | .326E+02 | 15.24 | |
| 4 | 5.08 | 32.5 | 62. | .105E-01 | .305E+02 | .609E+02 | 35.05 | |
| 5 | 6.35 | 31.6 | 77. | .129E-01 | .374E+02 | .748E+02 | 49.27 | X_{max} |
| 6 | 7.62 | 31.6 | 62. | .104E-01 | .301E+02 | .603E+02 | 20.83 | |
| 7 | 8.89 | 32.1 | 52. | .879E-02 | .255E+02 | .510E+02 | 7.62 | |
| 8 | 10.16 | 32.7 | 47. | .800E-02 | .232E+02 | .464E+02 | 4.57 | |
| 9 | 11.43 | 33.4 | 41. | .692E-02 | .201E+02 | .401E+02 | 3.05 | |
| 10 | 12.70 | 34.0 | 39. | .652E-02 | .189E+02 | .378E+02 | 3.05 | |
| 11 | 13.97 | 34.6 | 38. | .642E-02 | .186E+02 | .372E+02 | 0.51 | |
| 12 | 15.24 | 35.2 | 36. | .598E-02 | .173E+02 | .347E+02 | 1.52 | |
| 13 | 17.78 | 36.2 | 32. | .534E-02 | .155E+02 | .310E+02 | 4.23 | |
| 14 | 19.05 | 36.6 | 31. | .522E-02 | .151E+02 | .302E+02 | 3.56 | |
| 15 | 20.32 | 37.0 | 31. | .521E-02 | .151E+02 | .302E+02 | 1.18 | |
| 16 | 22.86 | 37.6 | 30. | .498E-02 | .144E+02 | .288E+02 | 1.52 | |
| 17 | 25.40 | 38.1 | 29. | .487E-02 | .141E+02 | .283E+02 | 0.25 | |
| 18 | 27.94 | 38.6 | 28. | .465E-02 | .135E+02 | .269E+02 | 1.90 | |
| 19 | 30.48 | 38.9 | 27. | .463E-02 | .134E+02 | .268E+02 | 0.25 | |
| 20 | 35.56 | 39.4 | 26. | .446E-02 | .129E+02 | .259E+02 | 0.25 | |
| 21 | 38.10 | 39.7 | 26. | .438E-02 | .127E+02 | .254E+02 | 0.51 | |
| 22 | 40.64 | 39.9 | 26. | .433E-02 | .126E+02 | .251E+02 | 0.28 | |
| 23 | 63.50 | 40.9 | 24. | .409E-02 | .119E+02 | .237E+02 | 0.21 | |
| 24 | 76.20 | 40.9 | 24. | .409E-02 | .119E+02 | .237E+02 | 0.25 | |
| 25 | 88.90 | 40.4 | 25. | .424E-02 | .123E+02 | .246E+02 | 0.26 | |

Table A.48: 1 in. cylinder with $S=0.5$ in.; $U = 5.0(m/s)$, $T = 23.2(^{\circ}C)$, $q = 432(W/m^2)$, $i = 90.0(A)$

**A.a-iv Data and Results for 1" cylinder in Different
Velocities; $S = 1"$**

Case: 1twb-30a

Date and time of experiment: Oct.10,1992, 16:45

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _Z | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 39.3 | | | | | | |
| 2 | 2.54 | 38.3 | 122. | .342E-02 | .120E+03 | .120E+03 | 0.76 | |
| 3 | 3.81 | 37.3 | 124. | .346E-02 | .121E+03 | .121E+03 | 4.79 | |
| 4 | 5.08 | 36.0 | 142. | .399E-02 | .139E+03 | .139E+03 | 1.13 | |
| 5 | 6.35 | 34.6 | 174. | .487E-02 | .170E+03 | .170E+03 | 6.68 | |
| 6 | 7.62 | 33.7 | 191. | .536E-02 | .187E+03 | .187E+03 | 7.68 | |
| 7 | 8.89 | 33.4 | 195. | .545E-02 | .190E+03 | .190E+03 | 6.55 | X _{max} |
| 8 | 10.16 | 33.7 | 190. | .532E-02 | .186E+03 | .186E+03 | 6.68 | |
| 9 | 11.43 | 34.5 | 166. | .464E-02 | .162E+03 | .162E+03 | 0.50 | |
| 10 | 12.70 | 35.3 | 152. | .426E-02 | .149E+03 | .149E+03 | 0.63 | |
| 11 | 13.97 | 36.1 | 144. | .403E-02 | .141E+03 | .141E+03 | 0.50 | |
| 12 | 15.24 | 36.9 | 131. | .368E-02 | .128E+03 | .128E+03 | 2.31 | |
| 13 | 17.78 | 37.9 | 124. | .347E-02 | .121E+03 | .121E+03 | 0.04 | |
| 14 | 19.05 | 38.5 | 118. | .329E-02 | .115E+03 | .115E+03 | 1.64 | |
| 15 | 20.32 | 38.9 | 115. | .321E-02 | .112E+03 | .112E+03 | 1.43 | |
| 16 | 22.86 | 39.3 | 113. | .316E-02 | .110E+03 | .110E+03 | 0.09 | |
| 17 | 25.40 | 39.8 | 110. | .307E-02 | .107E+03 | .107E+03 | 0.25 | |
| 18 | 27.94 | 40.1 | 107. | .299E-02 | .104E+03 | .104E+03 | 0.57 | |
| 19 | 30.48 | 40.3 | 106. | .298E-02 | .104E+03 | .104E+03 | 0.03 | |
| 20 | 35.56 | 40.7 | 104. | .292E-02 | .102E+03 | .102E+03 | 0.09 | |
| 21 | 38.10 | 40.9 | 102. | .286E-02 | .998E+02 | .998E+02 | 0.54 | |
| 22 | 40.64 | 40.9 | 102. | .286E-02 | .100E+03 | .100E+03 | 0.02 | |
| 23 | 63.50 | 41.8 | 98. | .273E-02 | .953E+02 | .953E+02 | 0.01 | |
| 24 | 76.20 | 42.1 | 96. | .268E-02 | .935E+02 | .935E+02 | 0.00 | |
| 25 | 88.90 | 42.4 | 94. | .263E-02 | .919E+02 | .919E+02 | 0.04 | |

Table A.49: 1 in. cylinder with S=1 in.; $U = 30.1(m/s)$, $T = 23.9(^{\circ}C)$, $q = 1743(W/m^2)$, $i = 180.0(A)$

Case: 1twb-30b

Date and time of experiment: Oct.10,1992, 20:45

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 39.7 | | | | | | |
| 2 | 2.54 | 39.1 | 111. | .313E-02 | .109E+03 | .109E+03 | 7.25 | |
| 3 | 3.81 | 37.9 | 129. | .362E-02 | .126E+03 | .126E+03 | 1.25 | |
| 4 | 5.08 | 36.6 | 143. | .401E-02 | .140E+03 | .140E+03 | 1.13 | |
| 5 | 6.35 | 35.3 | 173. | .486E-02 | .169E+03 | .169E+03 | 6.25 | |
| 6 | 7.62 | 34.4 | 191. | .536E-02 | .187E+03 | .187E+03 | 7.63 | |
| 7 | 8.89 | 34.1 | 194. | .546E-02 | .190E+03 | .190E+03 | 6.50 | X_{max} |
| 8 | 10.16 | 34.4 | 190. | .535E-02 | .186E+03 | .186E+03 | 7.13 | |
| 9 | 11.43 | 35.2 | 165. | .462E-02 | .161E+03 | .161E+03 | 0.25 | |
| 10 | 12.70 | 36.0 | 151. | .424E-02 | .147E+03 | .147E+03 | 0.88 | |
| 11 | 13.97 | 36.8 | 143. | .402E-02 | .140E+03 | .140E+03 | 0.25 | |
| 12 | 15.24 | 37.6 | 131. | .369E-02 | .128E+03 | .128E+03 | 2.08 | |
| 13 | 17.78 | 38.7 | 124. | .348E-02 | .121E+03 | .121E+03 | 0.08 | |
| 14 | 19.05 | 39.2 | 117. | .330E-02 | .115E+03 | .115E+03 | 1.75 | |
| 15 | 20.32 | 39.6 | 115. | .322E-02 | .112E+03 | .112E+03 | 1.38 | |
| 16 | 22.86 | 40.0 | 113. | .317E-02 | .110E+03 | .110E+03 | 0.06 | |
| 17 | 25.40 | 40.5 | 110. | .308E-02 | .107E+03 | .107E+03 | 0.16 | |
| 18 | 27.94 | 40.8 | 107. | .300E-02 | .104E+03 | .104E+03 | 0.62 | |
| 19 | 30.48 | 41.0 | 106. | .298E-02 | .104E+03 | .104E+03 | 0.06 | |
| 20 | 38.10 | 41.7 | 102. | .286E-02 | .996E+02 | .996E+02 | 0.21 | |
| 21 | 40.64 | 41.8 | 102. | .286E-02 | .994E+02 | .994E+02 | 0.02 | |
| 22 | 50.80 | 42.1 | 99. | .279E-02 | .971E+02 | .971E+02 | 0.01 | |
| 23 | 63.50 | 42.7 | 96. | .271E-02 | .941E+02 | .941E+02 | 0.02 | |
| 24 | 76.20 | 43.1 | 94. | .264E-02 | .919E+02 | .919E+02 | 0.01 | |
| 25 | 88.90 | 43.5 | 92. | .259E-02 | .901E+02 | .901E+02 | 0.05 | |

Table A.50: 1 in. cylinder with $S=1$ in.; $U = 30.0(m/s)$, $T = 24.5(^{\circ}C)$,
 $q = 1757(W/m^2)$, $i = 180.0(A)$

Case: 1twb-27.5

Date and time of experiment: Oct.10,1992, 19:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.4 | | | | | | |
| 2 | 2.54 | 36.8 | 103. | .314E-02 | .101E+03 | .101E+03 | 7.11 | |
| 3 | 3.81 | 35.7 | 120. | .366E-02 | .117E+03 | .117E+03 | 0.95 | |
| 4 | 5.08 | 34.6 | 132. | .400E-02 | .129E+03 | .129E+03 | 2.06 | |
| 5 | 6.35 | 33.4 | 165. | .500E-02 | .161E+03 | .161E+03 | 7.75 | |
| 6 | 7.62 | 32.6 | 180. | .548E-02 | .176E+03 | .176E+03 | 8.22 | |
| 7 | 8.89 | 32.4 | 183. | .557E-02 | .179E+03 | .179E+03 | 6.96 | X_{max} |
| 8 | 10.16 | 32.6 | 180. | .548E-02 | .176E+03 | .176E+03 | 8.06 | |
| 9 | 11.43 | 33.3 | 153. | .465E-02 | .149E+03 | .149E+03 | 0.47 | |
| 10 | 12.70 | 34.0 | 142. | .430E-02 | .138E+03 | .138E+03 | 0.79 | |
| 11 | 13.97 | 34.6 | 134. | .408E-02 | .131E+03 | .131E+03 | 0.16 | |
| 12 | 15.24 | 35.3 | 124. | .376E-02 | .121E+03 | .121E+03 | 1.79 | |
| 13 | 17.78 | 36.3 | 115. | .351E-02 | .113E+03 | .113E+03 | 0.53 | |
| 14 | 19.05 | 36.7 | 110. | .335E-02 | .108E+03 | .108E+03 | 1.58 | |
| 15 | 20.32 | 37.0 | 108. | .328E-02 | .105E+03 | .105E+03 | 1.11 | |
| 16 | 22.86 | 37.5 | 105. | .319E-02 | .103E+03 | .103E+03 | 0.24 | |
| 17 | 25.40 | 37.9 | 102. | .310E-02 | .996E+02 | .996E+02 | 0.28 | |
| 18 | 27.94 | 38.2 | 99. | .302E-02 | .970E+02 | .970E+02 | 0.55 | |
| 19 | 30.48 | 38.4 | 98. | .299E-02 | .961E+02 | .961E+02 | 0.22 | |
| 20 | 38.10 | 38.6 | 97. | .295E-02 | .949E+02 | .949E+02 | 0.06 | |
| 21 | 40.64 | 38.6 | 97. | .295E-02 | .948E+02 | .948E+02 | 0.10 | |
| 22 | 50.80 | 39.0 | 94. | .286E-02 | .919E+02 | .919E+02 | 0.08 | |
| 23 | 63.50 | 39.1 | 94. | .285E-02 | .917E+02 | .917E+02 | 0.14 | |
| 24 | 76.20 | 40.1 | 88. | .267E-02 | .859E+02 | .859E+02 | 0.11 | |
| 25 | 88.90 | 40.3 | 86. | .263E-02 | .845E+02 | .845E+02 | 0.04 | |

Table A.51: 1 in. cylinder with $S=1$ in.; $U = 27.7(m/s)$, $T = 24.3(^{\circ}C)$, $q = 1389(W/m^2)$, $i = 160.0(A)$

Case: 1twb-25

Date and time of experiment: Oct.10,1992, 19:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 38.5 | | | | | | |
| 2 | 2.54 | 37.9 | 95. | .321E-02 | .931E+02 | .931E+02 | 8.03 | |
| 3 | 3.81 | 36.8 | 111. | .374E-02 | .108E+03 | .108E+03 | 1.73 | |
| 4 | 5.08 | 35.5 | 124. | .419E-02 | .121E+03 | .121E+03 | 0.79 | |
| 5 | 6.35 | 34.3 | 151. | .510E-02 | .148E+03 | .148E+03 | 6.93 | |
| 6 | 7.62 | 33.4 | 168. | .566E-02 | .164E+03 | .164E+03 | 8.82 | |
| 7 | 8.89 | 33.2 | 172. | .578E-02 | .168E+03 | .168E+03 | 7.72 | X_{max} |
| 8 | 10.16 | 33.4 | 168. | .566E-02 | .164E+03 | .164E+03 | 8.19 | |
| 9 | 11.43 | 34.1 | 144. | .485E-02 | .141E+03 | .141E+03 | 0.32 | |
| 10 | 12.70 | 34.9 | 132. | .444E-02 | .129E+03 | .129E+03 | 1.10 | |
| 11 | 13.97 | 35.6 | 126. | .424E-02 | .123E+03 | .123E+03 | 0.79 | |
| 12 | 15.24 | 36.3 | 115. | .386E-02 | .112E+03 | .112E+03 | 2.20 | |
| 13 | 17.78 | 37.4 | 107. | .361E-02 | .105E+03 | .105E+03 | 0.42 | |
| 14 | 19.05 | 37.9 | 102. | .343E-02 | .993E+02 | .993E+02 | 1.89 | |
| 15 | 20.32 | 38.2 | 100. | .335E-02 | .972E+02 | .972E+02 | 1.31 | |
| 16 | 22.86 | 38.7 | 97. | .327E-02 | .949E+02 | .949E+02 | 0.24 | |
| 17 | 25.40 | 39.1 | 94. | .318E-02 | .922E+02 | .922E+02 | 0.24 | |
| 18 | 27.94 | 39.5 | 92. | .309E-02 | .896E+02 | .896E+02 | 0.63 | |
| 19 | 30.48 | 39.7 | 91. | .306E-02 | .889E+02 | .889E+02 | 0.04 | |
| 20 | 38.10 | 40.3 | 88. | .295E-02 | .855E+02 | .855E+02 | 0.24 | |
| 21 | 40.64 | 40.4 | 87. | .294E-02 | .854E+02 | .854E+02 | 0.05 | |
| 22 | 50.80 | 40.8 | 85. | .287E-02 | .832E+02 | .832E+02 | 0.02 | |
| 23 | 63.50 | 41.1 | 83. | .281E-02 | .814E+02 | .814E+02 | 0.00 | |
| 24 | 76.20 | 41.5 | 82. | .275E-02 | .798E+02 | .798E+02 | 0.01 | |
| 25 | 88.90 | 41.8 | 80. | .270E-02 | .784E+02 | .784E+02 | 0.05 | |

Table A.52: 1 in. cylinder with $S=1$ in.; $U = 25.0(m/s)$, $T = 24.4(^{\circ}C)$, $q = 1395(W/m^2)$, $i = 160.0(A)$

Case: 1twb-22.5

Date and time of experiment: Oct.10,1992, 18:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.8 | | | | | | |
| 2 | 2.54 | 36.3 | 89. | .334E-02 | .869E+02 | .869E+02 | 8.55 | |
| 3 | 3.81 | 35.3 | 103. | .387E-02 | .101E+03 | .101E+03 | 2.55 | |
| 4 | 5.08 | 34.2 | 116. | .437E-02 | .114E+03 | .114E+03 | 0.91 | |
| 5 | 6.35 | 33.0 | 143. | .536E-02 | .139E+03 | .139E+03 | 7.64 | |
| 6 | 7.62 | 32.2 | 157. | .591E-02 | .154E+03 | .154E+03 | 8.74 | |
| 7 | 8.89 | 31.9 | 161. | .607E-02 | .158E+03 | .158E+03 | 8.01 | X_{max} |
| 8 | 10.16 | 32.1 | 158. | .596E-02 | .155E+03 | .155E+03 | 8.01 | |
| 9 | 11.43 | 32.7 | 138. | .520E-02 | .135E+03 | .135E+03 | 1.09 | |
| 10 | 12.70 | 33.4 | 127. | .477E-02 | .124E+03 | .124E+03 | 0.18 | |
| 11 | 13.97 | 34.0 | 120. | .452E-02 | .117E+03 | .117E+03 | 0.91 | |
| 12 | 15.24 | 34.7 | 109. | .408E-02 | .106E+03 | .106E+03 | 2.43 | |
| 13 | 17.78 | 35.7 | 102. | .383E-02 | .994E+02 | .994E+02 | 0.12 | |
| 14 | 19.05 | 36.2 | 96. | .359E-02 | .933E+02 | .933E+02 | 2.37 | |
| 15 | 20.32 | 36.6 | 94. | .352E-02 | .915E+02 | .915E+02 | 1.52 | |
| 16 | 22.86 | 37.0 | 91. | .344E-02 | .894E+02 | .894E+02 | 0.23 | |
| 17 | 25.40 | 37.4 | 89. | .333E-02 | .866E+02 | .866E+02 | 0.27 | |
| 18 | 27.94 | 37.8 | 86. | .323E-02 | .839E+02 | .839E+02 | 0.73 | |
| 19 | 30.48 | 38.0 | 85. | .321E-02 | .835E+02 | .835E+02 | 0.14 | |
| 20 | 35.56 | 38.5 | 82. | .308E-02 | .801E+02 | .801E+02 | 0.56 | |
| 21 | 38.10 | 38.6 | 82. | .309E-02 | .804E+02 | .804E+02 | 0.14 | |
| 22 | 40.64 | 38.6 | 82. | .307E-02 | .798E+02 | .798E+02 | 0.00 | |
| 23 | 63.50 | 39.4 | 78. | .292E-02 | .758E+02 | .758E+02 | 0.02 | |
| 24 | 76.20 | 39.7 | 76. | .287E-02 | .745E+02 | .745E+02 | 0.01 | |
| 25 | 88.90 | 39.9 | 75. | .283E-02 | .736E+02 | .736E+02 | 0.03 | |

Table A.53: 1 in. cylinder with $S=1$ in.; $U = 22.4(m/s)$, $T = 23.9(^{\circ}C)$,
 $q = 1207(W/m^2)$, $i = 150.0(A)$

Case: 1twb-20

Date and time of experiment: Oct.10,1992, 19:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 38.4 | | | | | | |
| 2 | 2.54 | 37.9 | 80. | .337E-02 | .778E+02 | .778E+02 | 9.91 | |
| 3 | 3.81 | 36.9 | 92. | .391E-02 | .902E+02 | .902E+02 | 3.60 | |
| 4 | 5.08 | 35.6 | 105. | .445E-02 | .103E+03 | .103E+03 | 1.08 | |
| 5 | 6.35 | 34.3 | 130. | .549E-02 | .127E+03 | .127E+03 | 8.29 | |
| 6 | 7.62 | 33.4 | 144. | .611E-02 | .141E+03 | .141E+03 | 10.45 | |
| 7 | 8.89 | 33.2 | 147. | .620E-02 | .143E+03 | .143E+03 | 8.83 | X_{max} |
| 8 | 10.16 | 33.4 | 143. | .605E-02 | .140E+03 | .140E+03 | 8.65 | |
| 9 | 11.43 | 34.1 | 123. | .520E-02 | .120E+03 | .120E+03 | 0.54 | |
| 10 | 12.70 | 34.8 | 113. | .480E-02 | .111E+03 | .111E+03 | 0.36 | |
| 11 | 13.97 | 35.5 | 107. | .455E-02 | .105E+03 | .105E+03 | 0.54 | |
| 12 | 15.24 | 36.3 | 98. | .416E-02 | .960E+02 | .960E+02 | 1.98 | |
| 13 | 17.78 | 37.4 | 91. | .386E-02 | .890E+02 | .890E+02 | 0.54 | |
| 14 | 19.05 | 38.0 | 86. | .365E-02 | .842E+02 | .842E+02 | 2.16 | |
| 15 | 20.32 | 38.4 | 84. | .357E-02 | .825E+02 | .825E+02 | 1.38 | |
| 16 | 22.86 | 39.0 | 82. | .346E-02 | .799E+02 | .799E+02 | 0.50 | |
| 17 | 25.40 | 39.4 | 79. | .336E-02 | .776E+02 | .776E+02 | 0.23 | |
| 18 | 27.94 | 39.9 | 77. | .325E-02 | .750E+02 | .750E+02 | 0.86 | |
| 19 | 30.48 | 40.1 | 76. | .323E-02 | .745E+02 | .745E+02 | 0.02 | |
| 20 | 38.10 | 40.8 | 73. | .309E-02 | .712E+02 | .712E+02 | 0.25 | |
| 21 | 40.64 | 40.9 | 73. | .307E-02 | .709E+02 | .709E+02 | 0.02 | |
| 22 | 50.80 | 41.4 | 71. | .299E-02 | .691E+02 | .691E+02 | 0.03 | |
| 23 | 63.50 | 41.8 | 69. | .292E-02 | .674E+02 | .674E+02 | 0.03 | |
| 24 | 76.20 | 42.0 | 68. | .288E-02 | .666E+02 | .666E+02 | 0.01 | |
| 25 | 88.90 | 42.2 | 68. | .286E-02 | .660E+02 | .660E+02 | 0.03 | |

Table A.54: 1 in. cylinder with $S=1$ in.; $U = 19.9(m/s)$, $T = 24.1(^{\circ}C)$, $q = 1219(W/m^2)$, $i = 150.0(A)$

Case: 1twb-17.5

Date and time of experiment: Oct.10,1992, 17:30

| No. | X(cm) | T(°C) | h | St | Nu _s | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 36.9 | | | | | | |
| 2 | 2.54 | 36.5 | 72. | .346E-02 | .702E+02 | .702E+02 | 11.70 | |
| 3 | 3.81 | 35.5 | 85. | .409E-02 | .831E+02 | .831E+02 | 3.34 | |
| 4 | 5.08 | 34.4 | 95. | .459E-02 | .932E+02 | .932E+02 | 1.67 | |
| 5 | 6.35 | 33.2 | 119. | .572E-02 | .116E+03 | .116E+03 | 8.78 | |
| 6 | 7.62 | 32.4 | 131. | .633E-02 | .128E+03 | .128E+03 | 10.66 | |
| 7 | 8.89 | 32.2 | 134. | .644E-02 | .131E+03 | .131E+03 | 9.19 | X _{max} |
| 8 | 10.16 | 32.3 | 131. | .629E-02 | .128E+03 | .128E+03 | 8.78 | |
| 9 | 11.43 | 32.9 | 115. | .552E-02 | .112E+03 | .112E+03 | 1.88 | |
| 10 | 12.70 | 33.6 | 105. | .505E-02 | .102E+03 | .102E+03 | 0.00 | |
| 11 | 13.97 | 34.3 | 99. | .476E-02 | .966E+02 | .966E+02 | 0.63 | |
| 12 | 15.24 | 35.0 | 90. | .434E-02 | .881E+02 | .881E+02 | 2.16 | |
| 13 | 17.78 | 36.1 | 84. | .402E-02 | .816E+02 | .816E+02 | 0.49 | |
| 14 | 19.05 | 36.6 | 79. | .378E-02 | .768E+02 | .768E+02 | 2.51 | |
| 15 | 20.32 | 37.0 | 77. | .371E-02 | .753E+02 | .753E+02 | 1.46 | |
| 16 | 22.86 | 37.6 | 74. | .359E-02 | .728E+02 | .728E+02 | 0.57 | |
| 17 | 25.40 | 38.1 | 72. | .348E-02 | .705E+02 | .705E+02 | 0.31 | |
| 18 | 27.94 | 38.5 | 70. | .336E-02 | .682E+02 | .682E+02 | 0.84 | |
| 19 | 30.48 | 38.8 | 69. | .332E-02 | .675E+02 | .675E+02 | 0.23 | |
| 20 | 35.56 | 39.2 | 68. | .326E-02 | .661E+02 | .661E+02 | 0.26 | |
| 21 | 38.10 | 39.4 | 66. | .317E-02 | .643E+02 | .643E+02 | 0.73 | |
| 22 | 40.64 | 39.6 | 66. | .317E-02 | .642E+02 | .642E+02 | 0.04 | |
| 23 | 63.50 | 40.4 | 62. | .301E-02 | .610E+02 | .610E+02 | 0.04 | |
| 24 | 76.20 | 40.6 | 62. | .297E-02 | .602E+02 | .602E+02 | 0.02 | |
| 25 | 88.90 | 40.8 | 61. | .295E-02 | .598E+02 | .598E+02 | 0.02 | |

Table A.55: 1 in. cylinder with S=1 in.; $U = 17.5(m/s)$, $T = 23.6(^{\circ}C)$, $q = 1051(W/m^2)$, $i = 140.0(A)$

Case: 1twb-15a

Date and time of experiment: Oct.10,1992, 17:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.8 | | | | | | |
| 2 | 2.54 | 36.4 | 63. | .351E-02 | .611E+02 | .611E+02 | 12.02 | |
| 3 | 3.81 | 35.4 | 75. | .420E-02 | .730E+02 | .730E+02 | 2.88 | |
| 4 | 5.08 | 34.3 | 83. | .465E-02 | .809E+02 | .809E+02 | 2.16 | |
| 5 | 6.35 | 33.1 | 103. | .580E-02 | .101E+03 | .101E+03 | 8.65 | |
| 6 | 7.62 | 32.3 | 116. | .651E-02 | .113E+03 | .113E+03 | 11.54 | |
| 7 | 8.89 | 32.0 | 121. | .677E-02 | .118E+03 | .118E+03 | 11.54 | X_{max} |
| 8 | 10.16 | 32.1 | 117. | .655E-02 | .114E+03 | .114E+03 | 9.61 | |
| 9 | 11.43 | 32.6 | 102. | .574E-02 | .999E+02 | .999E+02 | 2.16 | |
| 10 | 12.70 | 33.3 | 94. | .528E-02 | .919E+02 | .919E+02 | 0.48 | |
| 11 | 13.97 | 33.9 | 89. | .499E-02 | .868E+02 | .868E+02 | 1.20 | |
| 12 | 15.24 | 34.6 | 81. | .453E-02 | .788E+02 | .788E+02 | 1.92 | |
| 13 | 17.78 | 35.8 | 74. | .414E-02 | .721E+02 | .721E+02 | 0.96 | |
| 14 | 19.05 | 36.3 | 70. | .391E-02 | .679E+02 | .679E+02 | 2.64 | |
| 15 | 20.32 | 36.7 | 68. | .383E-02 | .667E+02 | .667E+02 | 1.44 | |
| 16 | 22.86 | 37.4 | 65. | .368E-02 | .640E+02 | .640E+02 | 0.84 | |
| 17 | 25.40 | 37.9 | 63. | .356E-02 | .620E+02 | .620E+02 | 0.42 | |
| 18 | 27.94 | 38.3 | 61. | .344E-02 | .599E+02 | .599E+02 | 0.90 | |
| 19 | 30.48 | 38.6 | 61. | .340E-02 | .591E+02 | .591E+02 | 0.28 | |
| 20 | 35.56 | 39.0 | 59. | .333E-02 | .578E+02 | .578E+02 | 0.24 | |
| 21 | 38.10 | 39.3 | 58. | .323E-02 | .562E+02 | .562E+02 | 0.84 | |
| 22 | 40.64 | 39.4 | 58. | .323E-02 | .562E+02 | .562E+02 | 0.05 | |
| 23 | 63.50 | 40.2 | 55. | .308E-02 | .535E+02 | .535E+02 | 0.05 | |
| 24 | 76.20 | 40.3 | 54. | .305E-02 | .531E+02 | .531E+02 | 0.04 | |
| 25 | 88.90 | 40.3 | 55. | .306E-02 | .533E+02 | .533E+02 | 0.01 | |

Table A.56: 1 in. cylinder with $S=1$ in.; $U = 15.0(m/s)$, $T = 23.5(^{\circ}C)$, $q = 914(W/m^2)$, $i = 130.0(A)$

Case: 1twb-15b

Date and time of experiment: Oct.10,1992, 20:15

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.2 | | | | | | |
| 2 | 2.54 | 36.8 | 62. | .343E-02 | .604E+02 | .604E+02 | 12.45 | |
| 3 | 3.81 | 35.9 | 73. | .406E-02 | .716E+02 | .716E+02 | 3.59 | |
| 4 | 5.08 | 34.9 | 81. | .449E-02 | .791E+02 | .791E+02 | 2.87 | |
| 5 | 6.35 | 33.7 | 102. | .563E-02 | .992E+02 | .992E+02 | 8.62 | |
| 6 | 7.62 | 32.8 | 114. | .631E-02 | .111E+03 | .111E+03 | 11.49 | |
| 7 | 8.89 | 32.5 | 119. | .657E-02 | .116E+03 | .116E+03 | 11.49 | X_{max} |
| 8 | 10.16 | 32.6 | 115. | .639E-02 | .113E+03 | .113E+03 | 10.06 | |
| 9 | 11.43 | 33.2 | 100. | .557E-02 | .981E+02 | .981E+02 | 1.92 | |
| 10 | 12.70 | 33.8 | 93. | .513E-02 | .904E+02 | .904E+02 | 0.24 | |
| 11 | 13.97 | 34.4 | 88. | .487E-02 | .859E+02 | .859E+02 | 1.44 | |
| 12 | 15.24 | 35.1 | 80. | .443E-02 | .780E+02 | .780E+02 | 1.76 | |
| 13 | 17.78 | 36.3 | 73. | .403E-02 | .711E+02 | .711E+02 | 1.12 | |
| 14 | 19.05 | 36.8 | 69. | .380E-02 | .671E+02 | .671E+02 | 2.87 | |
| 15 | 20.32 | 37.2 | 68. | .375E-02 | .661E+02 | .661E+02 | 1.36 | |
| 16 | 22.86 | 37.9 | 65. | .360E-02 | .635E+02 | .635E+02 | 0.78 | |
| 17 | 25.40 | 38.4 | 63. | .350E-02 | .616E+02 | .616E+02 | 0.24 | |
| 18 | 27.94 | 38.8 | 61. | .336E-02 | .592E+02 | .592E+02 | 1.14 | |
| 19 | 30.48 | 39.1 | 60. | .333E-02 | .588E+02 | .588E+02 | 0.08 | |
| 20 | 38.10 | 39.8 | 57. | .317E-02 | .560E+02 | .560E+02 | 0.28 | |
| 21 | 40.64 | 40.0 | 57. | .315E-02 | .555E+02 | .555E+02 | 0.10 | |
| 22 | 50.80 | 40.4 | 55. | .307E-02 | .541E+02 | .541E+02 | 0.03 | |
| 23 | 63.50 | 40.8 | 54. | .299E-02 | .527E+02 | .527E+02 | 0.06 | |
| 24 | 76.20 | 41.0 | 54. | .297E-02 | .523E+02 | .523E+02 | 0.03 | |
| 25 | 88.90 | 41.0 | 54. | .297E-02 | .523E+02 | .523E+02 | 0.00 | |

Table A.57: 1 in. cylinder with $S=1$ in.; $U = 15.2(m/s)$, $T = 23.8(^{\circ}C)$, $q = 917(W/m^2)$, $i = 130.0(A)$

Case: 1twb-12.5

Date and time of experiment: Oct.10.1992, 21:50

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.5 | | | | | | |
| 2 | 2.54 | 35.5 | 54. | .362E-02 | .528E+02 | .528E+02 | 16.81 | |
| 3 | 3.81 | 35.0 | 62. | .415E-02 | .606E+02 | .606E+02 | 9.12 | |
| 4 | 5.08 | 34.1 | 71. | .473E-02 | .691E+02 | .691E+02 | 4.56 | |
| 5 | 6.35 | 33.0 | 88. | .591E-02 | .863E+02 | .863E+02 | 7.12 | |
| 6 | 7.62 | 32.2 | 101. | .673E-02 | .984E+02 | .984E+02 | 11.68 | |
| 7 | 8.89 | 31.8 | 106. | .707E-02 | .103E+03 | .103E+03 | 11.96 | X_{max} |
| 8 | 10.16 | 31.9 | 105. | .701E-02 | .102E+03 | .102E+03 | 11.40 | |
| 9 | 11.43 | 32.3 | 92. | .618E-02 | .904E+02 | .904E+02 | 3.42 | |
| 10 | 12.70 | 32.9 | 85. | .565E-02 | .826E+02 | .826E+02 | 0.57 | |
| 11 | 13.97 | 33.4 | 81. | .540E-02 | .789E+02 | .789E+02 | 1.99 | |
| 12 | 15.24 | 34.1 | 73. | .490E-02 | .715E+02 | .715E+02 | 1.42 | |
| 13 | 17.78 | 35.2 | 66. | .441E-02 | .644E+02 | .644E+02 | 1.61 | |
| 14 | 19.05 | 35.7 | 62. | .418E-02 | .610E+02 | .610E+02 | 2.85 | |
| 15 | 20.32 | 36.1 | 62. | .414E-02 | .604E+02 | .604E+02 | 0.76 | |
| 16 | 22.86 | 36.7 | 58. | .390E-02 | .570E+02 | .570E+02 | 1.28 | |
| 17 | 25.40 | 37.2 | 57. | .379E-02 | .553E+02 | .553E+02 | 0.43 | |
| 18 | 27.94 | 37.7 | 55. | .365E-02 | .533E+02 | .533E+02 | 1.00 | |
| 19 | 30.48 | 38.0 | 54. | .360E-02 | .526E+02 | .526E+02 | 0.30 | |
| 20 | 38.10 | 38.6 | 51. | .344E-02 | .503E+02 | .503E+02 | 0.24 | |
| 21 | 40.64 | 38.8 | 51. | .341E-02 | .498E+02 | .498E+02 | 0.13 | |
| 22 | 50.80 | 39.2 | 50. | .332E-02 | .485E+02 | .485E+02 | 0.05 | |
| 23 | 63.50 | 39.6 | 49. | .324E-02 | .474E+02 | .474E+02 | 0.05 | |
| 24 | 76.20 | 39.8 | 48. | .321E-02 | .468E+02 | .468E+02 | 0.06 | |
| 25 | 88.90 | 39.7 | 48. | .321E-02 | .470E+02 | .470E+02 | 0.01 | |

Table A.58: 1 in. cylinder with $S=1$ in.; $U = 12.6(m/s)$, $T = 23.7(^{\circ}C)$,
 $q = 771(W/m^2)$, $i = 120.0(A)$

Case: 1twb-10

Date and time of experiment: Oct.10,1992, 22:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_L | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------------|
| 1 | 1.27 | 35.9 | | | | | | |
| 2 | 2.54 | 35.7 | 45. | .376E-02 | .436E+02 | .436E+02 | 17.17 | |
| 3 | 3.81 | 35.1 | 51. | .430E-02 | .499E+02 | .499E+02 | 10.10 | |
| 4 | 5.08 | 34.1 | 59. | .499E-02 | .578E+02 | .578E+02 | 4.38 | |
| 5 | 6.35 | 33.1 | 74. | .623E-02 | .723E+02 | .723E+02 | 7.41 | |
| 6 | 7.62 | 32.2 | 86. | .723E-02 | .839E+02 | .839E+02 | 13.47 | |
| 7 | 8.89 | 31.8 | 91. | .763E-02 | .885E+02 | .885E+02 | 13.47 | |
| 8 | 10.16 | 31.7 | 92. | .775E-02 | .899E+02 | .899E+02 | 14.48 | λ_{max} |
| 9 | 11.43 | 32.1 | 80. | .671E-02 | .778E+02 | .778E+02 | 3.70 | |
| 10 | 12.70 | 32.6 | 74. | .620E-02 | .719E+02 | .719E+02 | 1.35 | |
| 11 | 13.97 | 33.1 | 71. | .599E-02 | .694E+02 | .694E+02 | 3.70 | |
| 12 | 15.24 | 33.8 | 63. | .534E-02 | .620E+02 | .620E+02 | 1.23 | |
| 13 | 17.78 | 34.9 | 57. | .479E-02 | .556E+02 | .556E+02 | 1.23 | |
| 14 | 19.05 | 35.5 | 53. | .446E-02 | .518E+02 | .518E+02 | 3.70 | |
| 15 | 20.32 | 35.9 | 53. | .443E-02 | .513E+02 | .513E+02 | 1.12 | |
| 16 | 22.86 | 36.6 | 49. | .416E-02 | .482E+02 | .482E+02 | 1.51 | |
| 17 | 25.40 | 37.2 | 48. | .403E-02 | .467E+02 | .467E+02 | 0.50 | |
| 18 | 27.94 | 37.7 | 46. | .384E-02 | .446E+02 | .446E+02 | 1.51 | |
| 19 | 30.48 | 38.0 | 45. | .381E-02 | .441E+02 | .441E+02 | 0.29 | |
| 20 | 38.10 | 38.8 | 43. | .362E-02 | .419E+02 | .419E+02 | 0.29 | |
| 21 | 40.64 | 38.9 | 42. | .358E-02 | .415E+02 | .415E+02 | 0.20 | |
| 22 | 50.80 | 39.4 | 41. | .347E-02 | .403E+02 | .403E+02 | 0.08 | |
| 23 | 63.50 | 39.8 | 40. | .339E-02 | .393E+02 | .393E+02 | 0.09 | |
| 24 | 76.20 | 39.9 | 40. | .336E-02 | .390E+02 | .390E+02 | 0.09 | |
| 25 | 88.90 | 39.8 | 40. | .340E-02 | .394E+02 | .394E+02 | 0.05 | |

Table A.59: 1 in. cylinder with $S=1$ in.; $U = 10.0(m/s)$, $T = 23.6(^{\circ}C)$,
 $q = 652(W/m^2)$, $i = 110.0(A)$

Case: Itwb- 8.7

Date and time of experiment: Oct.10,1992, 22:15

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.5 | | | | | | |
| 2 | 2.54 | 36.6 | 41. | .390E-02 | .398E+02 | .398E+02 | 19.26 | |
| 3 | 3.81 | 36.0 | 45. | .432E-02 | .441E+02 | .441E+02 | 14.19 | |
| 4 | 5.08 | 35.1 | 53. | .512E-02 | .522E+02 | .522E+02 | 6.08 | |
| 5 | 6.35 | 34.0 | 68. | .651E-02 | .664E+02 | .664E+02 | 7.77 | |
| 6 | 7.62 | 33.1 | 78. | .746E-02 | .761E+02 | .761E+02 | 12.84 | |
| 7 | 8.89 | 32.6 | 84. | .801E-02 | .817E+02 | .817E+02 | 14.53 | |
| 8 | 10.16 | 32.5 | 85. | .815E-02 | .832E+02 | .832E+02 | 15.54 | X_{max} |
| 9 | 11.43 | 32.9 | 74. | .704E-02 | .718E+02 | .718E+02 | 4.65 | |
| 10 | 12.70 | 33.4 | 68. | .654E-02 | .668E+02 | .668E+02 | 2.03 | |
| 11 | 13.97 | 33.9 | 65. | .627E-02 | .640E+02 | .640E+02 | 3.38 | |
| 12 | 15.24 | 34.6 | 59. | .565E-02 | .577E+02 | .577E+02 | 0.79 | |
| 13 | 17.78 | 35.9 | 53. | .504E-02 | .514E+02 | .514E+02 | 1.46 | |
| 14 | 19.05 | 36.4 | 49. | .471E-02 | .480E+02 | .480E+02 | 3.72 | |
| 15 | 20.32 | 36.9 | 49. | .469E-02 | .479E+02 | .479E+02 | 0.56 | |
| 16 | 22.86 | 37.7 | 45. | .435E-02 | .444E+02 | .444E+02 | 1.94 | |
| 17 | 25.40 | 38.3 | 44. | .423E-02 | .431E+02 | .431E+02 | 0.51 | |
| 18 | 27.94 | 38.9 | 42. | .403E-02 | .411E+02 | .411E+02 | 1.52 | |
| 19 | 30.48 | 39.3 | 42. | .397E-02 | .405E+02 | .405E+02 | 0.44 | |
| 20 | 38.10 | 40.1 | 39. | .378E-02 | .386E+02 | .386E+02 | 0.28 | |
| 21 | 40.64 | 40.3 | 39. | .373E-02 | .381E+02 | .381E+02 | 0.25 | |
| 22 | 50.80 | 40.9 | 38. | .362E-02 | .369E+02 | .369E+02 | 0.09 | |
| 23 | 63.50 | 41.3 | 37. | .353E-02 | .360E+02 | .360E+02 | 0.08 | |
| 24 | 76.20 | 41.5 | 37. | .350E-02 | .357E+02 | .357E+02 | 0.12 | |
| 25 | 88.90 | 41.3 | 37. | .354E-02 | .361E+02 | .361E+02 | 0.06 | |

Table A.60: 1 in. cylinder with $S=1$ in.; $U = 8.8(m/s)$, $T = 23.7(^{\circ}C)$, $q = 650(W/m^2)$, $i = 110.0(A)$

Case: Itwb-7.5a

Date and time of experiment: Oct.10,1992, 21:30

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 34.4 | | | | | | |
| 2 | 2.54 | 34.9 | 35. | .389E-02 | .339E+02 | .339E+02 | 27.24 | |
| 3 | 3.81 | 34.8 | 38. | .429E-02 | .373E+02 | .373E+02 | 20.74 | |
| 4 | 5.08 | 34.2 | 46. | .514E-02 | .447E+02 | .447E+02 | 10.57 | |
| 5 | 6.35 | 33.3 | 59. | .665E-02 | .579E+02 | .579E+02 | 5.69 | |
| 6 | 7.62 | 32.5 | 69. | .770E-02 | .670E+02 | .670E+02 | 12.61 | |
| 7 | 8.89 | 32.0 | 73. | .824E-02 | .717E+02 | .717E+02 | 14.23 | |
| 8 | 10.16 | 31.9 | 76. | .856E-02 | .744E+02 | .744E+02 | 17.08 | X_{max} |
| 9 | 11.43 | 32.2 | 65. | .733E-02 | .638E+02 | .638E+02 | 4.07 | |
| 10 | 12.70 | 32.6 | 62. | .692E-02 | .602E+02 | .602E+02 | 2.85 | |
| 11 | 13.97 | 33.1 | 59. | .662E-02 | .576E+02 | .576E+02 | 3.66 | |
| 12 | 15.24 | 33.7 | 53. | .594E-02 | .517E+02 | .517E+02 | 1.35 | |
| 13 | 17.78 | 34.7 | 48. | .540E-02 | .470E+02 | .470E+02 | 1.08 | |
| 14 | 19.05 | 35.2 | 45. | .502E-02 | .437E+02 | .437E+02 | 4.07 | |
| 15 | 20.32 | 35.6 | 45. | .511E-02 | .444E+02 | .444E+02 | 0.81 | |
| 16 | 22.86 | 36.4 | 41. | .462E-02 | .402E+02 | .402E+02 | 2.64 | |
| 17 | 25.40 | 37.0 | 40. | .453E-02 | .394E+02 | .394E+02 | 0.41 | |
| 18 | 27.94 | 37.5 | 38. | .430E-02 | .374E+02 | .374E+02 | 1.63 | |
| 19 | 30.48 | 37.8 | 38. | .424E-02 | .369E+02 | .369E+02 | 0.54 | |
| 20 | 38.10 | 38.6 | 36. | .404E-02 | .351E+02 | .351E+02 | 0.17 | |
| 21 | 40.64 | 38.8 | 35. | .397E-02 | .345E+02 | .345E+02 | 0.45 | |
| 22 | 50.80 | 39.3 | 34. | .387E-02 | .337E+02 | .337E+02 | 0.05 | |
| 23 | 63.50 | 39.7 | 34. | .377E-02 | .328E+02 | .328E+02 | 0.11 | |
| 24 | 76.20 | 39.9 | 33. | .373E-02 | .325E+02 | .325E+02 | 0.13 | |
| 25 | 88.90 | 39.7 | 34. | .377E-02 | .328E+02 | .328E+02 | 0.06 | |

Table A.61: 1 in. cylinder with $S=1$ in.; $U = 7.5(m/s)$, $T = 23.6(^{\circ}C)$,
 $q = 540(W/m^2)$, $i = 100.0(A)$

Case: 1twb-7.5b

Date and time of experiment: Oct.10,1992, 23:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.1 | | | | | | |
| 2 | 2.54 | 35.1 | 35. | .393E-02 | .346E+02 | .346E+02 | 21.46 | |
| 3 | 3.81 | 34.7 | 39. | .437E-02 | .385E+02 | .385E+02 | 16.09 | |
| 4 | 5.08 | 33.8 | 47. | .515E-02 | .454E+02 | .454E+02 | 8.25 | |
| 5 | 6.35 | 32.8 | 62. | .683E-02 | .602E+02 | .602E+02 | 9.49 | |
| 6 | 7.62 | 32.0 | 70. | .778E-02 | .685E+02 | .685E+02 | 14.03 | |
| 7 | 8.89 | 31.5 | 75. | .828E-02 | .730E+02 | .730E+02 | 14.86 | |
| 8 | 10.16 | 31.4 | 75. | .837E-02 | .737E+02 | .737E+02 | 14.44 | X_{max} |
| 9 | 11.43 | 31.6 | 69. | .760E-02 | .670E+02 | .670E+02 | 7.02 | |
| 10 | 12.70 | 32.1 | 63. | .696E-02 | .614E+02 | .614E+02 | 2.89 | |
| 11 | 13.97 | 32.5 | 61. | .673E-02 | .593E+02 | .593E+02 | 4.95 | |
| 12 | 15.24 | 33.1 | 54. | .598E-02 | .527E+02 | .527E+02 | 0.69 | |
| 13 | 17.78 | 34.3 | 48. | .531E-02 | .468E+02 | .468E+02 | 1.51 | |
| 14 | 19.05 | 34.8 | 44. | .491E-02 | .433E+02 | .433E+02 | 4.54 | |
| 15 | 20.32 | 35.2 | 44. | .493E-02 | .435E+02 | .435E+02 | 0.69 | |
| 16 | 22.86 | 36.0 | 41. | .458E-02 | .403E+02 | .403E+02 | 1.86 | |
| 17 | 25.40 | 36.6 | 40. | .443E-02 | .391E+02 | .391E+02 | 0.52 | |
| 18 | 27.94 | 37.1 | 38. | .421E-02 | .371E+02 | .371E+02 | 1.65 | |
| 19 | 30.48 | 37.5 | 37. | .414E-02 | .365E+02 | .365E+02 | 0.55 | |
| 20 | 38.10 | 38.3 | 35. | .392E-02 | .346E+02 | .346E+02 | 0.38 | |
| 21 | 40.64 | 38.5 | 35. | .388E-02 | .342E+02 | .342E+02 | 0.28 | |
| 22 | 50.80 | 39.1 | 34. | .375E-02 | .331E+02 | .331E+02 | 0.12 | |
| 23 | 63.50 | 39.4 | 33. | .366E-02 | .323E+02 | .323E+02 | 0.12 | |
| 24 | 76.20 | 39.5 | 33. | .364E-02 | .320E+02 | .320E+02 | 0.14 | |
| 25 | 88.90 | 39.3 | 33. | .370E-02 | .326E+02 | .326E+02 | 0.10 | |

Table A.62: 1 in. cylinder with $S=1$ in.; $U = 7.6(m/s)$, $T = 23.3(^{\circ}C)$, $q = 532(W/m^2)$, $i = 100.0(A)$

Case: 1twb-06

Date and time of experiment: Oct.10,1992, 23:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.3 | | | | | | |
| 2 | 2.54 | 35.2 | 28. | .395E-02 | .275E+02 | .275E+02 | 22.00 | |
| 3 | 3.81 | 34.7 | 31. | .437E-02 | .304E+02 | .304E+02 | 17.40 | |
| 4 | 5.08 | 33.8 | 36. | .504E-02 | .351E+02 | .351E+02 | 11.77 | |
| 5 | 6.35 | 32.7 | 51. | .711E-02 | .495E+02 | .495E+02 | 11.77 | |
| 6 | 7.62 | 31.9 | 58. | .821E-02 | .571E+02 | .571E+02 | 17.40 | |
| 7 | 8.89 | 31.4 | 62. | .869E-02 | .604E+02 | .604E+02 | 16.89 | |
| 8 | 10.16 | 31.2 | 65. | .915E-02 | .637E+02 | .637E+02 | 20.47 | X_{max} |
| 9 | 11.43 | 31.4 | 56. | .785E-02 | .546E+02 | .546E+02 | 6.14 | |
| 10 | 12.70 | 31.8 | 53. | .739E-02 | .514E+02 | .514E+02 | 4.09 | |
| 11 | 13.97 | 32.2 | 52. | .725E-02 | .504E+02 | .504E+02 | 7.16 | |
| 12 | 15.24 | 32.7 | 45. | .637E-02 | .444E+02 | .444E+02 | 0.17 | |
| 13 | 17.78 | 33.9 | 40. | .558E-02 | .388E+02 | .388E+02 | 1.88 | |
| 14 | 19.05 | 34.4 | 37. | .517E-02 | .360E+02 | .360E+02 | 4.61 | |
| 15 | 20.32 | 34.8 | 37. | .516E-02 | .359E+02 | .359E+02 | 1.19 | |
| 16 | 22.86 | 35.6 | 34. | .481E-02 | .335E+02 | .335E+02 | 1.79 | |
| 17 | 25.40 | 36.2 | 33. | .462E-02 | .322E+02 | .322E+02 | 0.77 | |
| 18 | 27.94 | 36.8 | 31. | .437E-02 | .304E+02 | .304E+02 | 2.05 | |
| 19 | 30.48 | 37.2 | 31. | .430E-02 | .299E+02 | .299E+02 | 0.68 | |
| 20 | 38.10 | 38.1 | 29. | .404E-02 | .281E+02 | .281E+02 | 0.53 | |
| 21 | 40.64 | 38.3 | 28. | .399E-02 | .278E+02 | .278E+02 | 0.38 | |
| 22 | 50.80 | 38.9 | 27. | .385E-02 | .268E+02 | .268E+02 | 0.20 | |
| 23 | 63.50 | 39.3 | 27. | .376E-02 | .262E+02 | .262E+02 | 0.17 | |
| 24 | 76.20 | 39.3 | 27. | .377E-02 | .262E+02 | .262E+02 | 0.29 | |
| 25 | 88.90 | 39.9 | 26. | .361E-02 | .251E+02 | .251E+02 | 0.31 | |

Table A.63: 1 in. cylinder with $S=1$ in.; $U = 6.0(m/s)$, $T = 23.3(^{\circ}C)$, $q = 429(W/m^2)$, $i = 90.0(A)$

Case: 1twb-05

Date and time of experiment: Oct.10,1992, 22:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.7 | | | | | | |
| 2 | 2.54 | 36.8 | 24. | .397E-02 | .235E+02 | .235E+02 | 27.27 | |
| 3 | 3.81 | 36.3 | 27. | .444E-02 | .263E+02 | .263E+02 | 21.32 | |
| 4 | 5.08 | 35.4 | 31. | .510E-02 | .302E+02 | .302E+02 | 15.87 | |
| 5 | 6.35 | 34.3 | 46. | .756E-02 | .447E+02 | .447E+02 | 12.40 | |
| 6 | 7.62 | 33.3 | 53. | .869E-02 | .514E+02 | .514E+02 | 17.85 | |
| 7 | 8.89 | 32.7 | 57. | .940E-02 | .556E+02 | .556E+02 | 19.83 | |
| 8 | 10.16 | 32.5 | 58. | .955E-02 | .565E+02 | .565E+02 | 19.34 | X_{max} |
| 9 | 11.43 | 32.7 | 51. | .845E-02 | .500E+02 | .500E+02 | 7.93 | |
| 10 | 12.70 | 33.1 | 48. | .792E-02 | .468E+02 | .468E+02 | 4.96 | |
| 11 | 13.97 | 33.5 | 47. | .774E-02 | .458E+02 | .458E+02 | 7.44 | |
| 12 | 15.24 | 34.1 | 41. | .682E-02 | .403E+02 | .403E+02 | 0.33 | |
| 13 | 17.78 | 35.4 | 36. | .601E-02 | .356E+02 | .356E+02 | 1.32 | |
| 14 | 19.05 | 36.0 | 33. | .552E-02 | .327E+02 | .327E+02 | 4.96 | |
| 15 | 20.32 | 36.4 | 34. | .555E-02 | .328E+02 | .328E+02 | 0.83 | |
| 16 | 22.86 | 37.4 | 31. | .512E-02 | .303E+02 | .303E+02 | 2.23 | |
| 17 | 25.40 | 38.1 | 30. | .493E-02 | .292E+02 | .292E+02 | 0.87 | |
| 18 | 27.94 | 38.8 | 28. | .466E-02 | .276E+02 | .276E+02 | 2.11 | |
| 19 | 30.48 | 39.2 | 28. | .458E-02 | .271E+02 | .271E+02 | 0.70 | |
| 20 | 38.10 | 40.4 | 26. | .428E-02 | .253E+02 | .253E+02 | 0.54 | |
| 21 | 40.64 | 40.7 | 25. | .421E-02 | .249E+02 | .249E+02 | 0.55 | |
| 22 | 50.80 | 41.4 | 25. | .406E-02 | .240E+02 | .240E+02 | 0.21 | |
| 23 | 63.50 | 41.9 | 24. | .394E-02 | .233E+02 | .233E+02 | 0.22 | |
| 24 | 76.20 | 41.9 | 24. | .393E-02 | .232E+02 | .232E+02 | 0.31 | |
| 25 | 88.90 | 41.4 | 25. | .407E-02 | .241E+02 | .241E+02 | 0.28 | |

Table A.64: 1 in. cylinder with $S=1$ in.; $U = 5.1(m/s)$, $T = 23.4(^{\circ}C)$,
 $q = 443(W/m^2)$, $i = 90.0(A)$

**A.a-v Data and Results for 1" cylinder in Different
Velocities; $S = 1.5''$, $D = 4''$**

Case: 1twc-30a

Date and time of experiment: Oct.11,1992, 01:15

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 38.0 | | | | | | |
| 2 | 2.54 | 38.1 | 106. | .298E-02 | .155E+03 | .103E+03 | 9.81 | |
| 3 | 3.81 | 37.5 | 120. | .336E-02 | .175E+03 | .117E+03 | 2.45 | |
| 4 | 5.08 | 36.7 | 126. | .353E-02 | .184E+03 | .123E+03 | 3.54 | |
| 5 | 6.35 | 35.7 | 145. | .408E-02 | .213E+03 | .142E+03 | 2.18 | |
| 6 | 7.62 | 34.8 | 156. | .440E-02 | .229E+03 | .153E+03 | 1.64 | |
| 7 | 8.89 | 34.1 | 170. | .480E-02 | .250E+03 | .167E+03 | 2.86 | |
| 8 | 10.16 | 33.5 | 185. | .520E-02 | .271E+03 | .181E+03 | 5.32 | |
| 9 | 11.43 | 33.4 | 185. | .521E-02 | .271E+03 | .181E+03 | 3.82 | X _{mar} |
| 10 | 12.70 | 33.5 | 182. | .512E-02 | .267E+03 | .178E+03 | 3.54 | |
| 11 | 13.97 | 33.9 | 174. | .489E-02 | .255E+03 | .170E+03 | 3.00 | |
| 12 | 15.24 | 34.5 | 158. | .445E-02 | .232E+03 | .154E+03 | 0.27 | |
| 13 | 17.78 | 35.7 | 143. | .403E-02 | .210E+03 | .140E+03 | 0.64 | |
| 14 | 19.05 | 36.3 | 132. | .371E-02 | .193E+03 | .129E+03 | 1.91 | |
| 15 | 20.32 | 36.8 | 127. | .358E-02 | .187E+03 | .124E+03 | 1.32 | |
| 16 | 22.86 | 37.6 | 121. | .342E-02 | .178E+03 | .119E+03 | 0.44 | |
| 17 | 25.40 | 38.2 | 116. | .327E-02 | .170E+03 | .114E+03 | 0.37 | |
| 18 | 27.94 | 38.7 | 112. | .315E-02 | .164E+03 | .109E+03 | 0.72 | |
| 19 | 30.48 | 38.9 | 110. | .310E-02 | .162E+03 | .108E+03 | 0.13 | |
| 20 | 38.10 | 39.6 | 106. | .298E-02 | .155E+03 | .103E+03 | 0.21 | |
| 21 | 40.64 | 39.6 | 106. | .297E-02 | .155E+03 | .103E+03 | 0.03 | |
| 22 | 50.80 | 40.0 | 103. | .289E-02 | .151E+03 | .100E+03 | 0.01 | |
| 23 | 63.50 | 40.5 | 100. | .281E-02 | .146E+03 | .975E+02 | 0.01 | |
| 24 | 76.20 | 40.9 | 98. | .274E-02 | .143E+03 | .953E+02 | 0.01 | |
| 25 | 88.90 | 41.1 | 96. | .270E-02 | .141E+03 | .937E+02 | 0.04 | |

Table A.65: 1 in. cylinder with S=1.5 in.; $U = 30.2(m/s)$, $T = 24.4(^{\circ}C)$, $q = 1611(W/m^2)$, $i = 173.3(A)$

Case: 1twc-30b

Date and time of experiment: Oct.11,1992, 03:30

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 38.3 | | | | | | |
| 2 | 2.54 | 38.2 | 103. | .292E-02 | .151E+03 | .101E+03 | 8.45 | |
| 3 | 3.81 | 37.5 | 117. | .331E-02 | .171E+03 | .114E+03 | 1.55 | |
| 4 | 5.08 | 36.7 | 123. | .349E-02 | .181E+03 | .120E+03 | 2.54 | |
| 5 | 6.35 | 35.7 | 141. | .398E-02 | .206E+03 | .137E+03 | 2.11 | |
| 6 | 7.62 | 34.8 | 151. | .427E-02 | .221E+03 | .147E+03 | 1.41 | |
| 7 | 8.89 | 34.1 | 165. | .467E-02 | .241E+03 | .161E+03 | 2.82 | |
| 8 | 10.16 | 33.5 | 178. | .504E-02 | .261E+03 | .174E+03 | 4.79 | |
| 9 | 11.43 | 33.3 | 182. | .514E-02 | .266E+03 | .177E+03 | 4.51 | X_{max} |
| 10 | 12.70 | 33.4 | 178. | .504E-02 | .261E+03 | .174E+03 | 3.66 | |
| 11 | 13.97 | 33.8 | 170. | .482E-02 | .250E+03 | .166E+03 | 3.24 | |
| 12 | 15.24 | 34.4 | 155. | .440E-02 | .228E+03 | .152E+03 | 0.09 | |
| 13 | 17.78 | 35.6 | 139. | .393E-02 | .203E+03 | .136E+03 | 0.38 | |
| 14 | 19.05 | 36.3 | 128. | .364E-02 | .188E+03 | .125E+03 | 1.83 | |
| 15 | 20.32 | 36.8 | 123. | .349E-02 | .180E+03 | .120E+03 | 1.74 | |
| 16 | 22.86 | 37.5 | 119. | .336E-02 | .174E+03 | .116E+03 | 0.28 | |
| 17 | 25.40 | 38.1 | 113. | .321E-02 | .166E+03 | .111E+03 | 0.35 | |
| 18 | 27.94 | 38.6 | 109. | .309E-02 | .160E+03 | .106E+03 | 0.85 | |
| 19 | 30.48 | 38.8 | 108. | .306E-02 | .158E+03 | .105E+03 | 0.02 | |
| 20 | 38.10 | 39.5 | 103. | .290E-02 | .150E+03 | .100E+03 | 0.26 | |
| 21 | 40.64 | 39.6 | 102. | .290E-02 | .150E+03 | .999E+02 | 0.02 | |
| 22 | 50.80 | 40.0 | 100. | .282E-02 | .146E+03 | .972E+02 | 0.02 | |
| 23 | 63.50 | 40.4 | 97. | .275E-02 | .142E+03 | .948E+02 | 0.02 | |
| 24 | 76.20 | 40.7 | 96. | .271E-02 | .140E+03 | .933E+02 | 0.01 | |
| 25 | 88.90 | 41.0 | 94. | .265E-02 | .137E+03 | .915E+02 | 0.05 | |

Table A.66: 1 in. cylinder with $S=1.5$ in.; $U = 30.0(m/s)$, $T = 24.4(^{\circ}C)$, $q = 1559(W/m^2)$, $i = 170.0(A)$

Case: 1twc-27.5

Date and time of experiment: Oct.11,1992, 02:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.5 | | | | | | |
| 2 | 2.54 | 37.4 | 97. | .298E-02 | .142E+03 | .950E+02 | 8.46 | |
| 3 | 3.81 | 36.9 | 108. | .332E-02 | .159E+03 | .106E+03 | 2.55 | |
| 4 | 5.08 | 36.1 | 114. | .350E-02 | .167E+03 | .111E+03 | 3.67 | |
| 5 | 6.35 | 35.1 | 132. | .406E-02 | .194E+03 | .129E+03 | 2.39 | |
| 6 | 7.62 | 34.3 | 143. | .438E-02 | .209E+03 | .139E+03 | 1.76 | |
| 7 | 8.89 | 33.6 | 156. | .478E-02 | .228E+03 | .152E+03 | 2.87 | |
| 8 | 10.16 | 33.0 | 171. | .524E-02 | .250E+03 | .167E+03 | 6.06 | |
| 9 | 11.43 | 32.9 | 171. | .525E-02 | .251E+03 | .167E+03 | 4.31 | X_{max} |
| 10 | 12.70 | 33.0 | 168. | .516E-02 | .246E+03 | .164E+03 | 3.83 | |
| 11 | 13.97 | 33.3 | 161. | .494E-02 | .236E+03 | .157E+03 | 3.51 | |
| 12 | 15.24 | 33.9 | 146. | .447E-02 | .214E+03 | .142E+03 | 0.27 | |
| 13 | 17.78 | 35.0 | 132. | .404E-02 | .193E+03 | .129E+03 | 0.69 | |
| 14 | 19.05 | 35.6 | 121. | .372E-02 | .178E+03 | .118E+03 | 2.07 | |
| 15 | 20.32 | 36.1 | 117. | .359E-02 | .171E+03 | .114E+03 | 1.44 | |
| 16 | 22.86 | 36.8 | 112. | .342E-02 | .163E+03 | .109E+03 | 0.40 | |
| 17 | 25.40 | 37.4 | 106. | .326E-02 | .156E+03 | .104E+03 | 0.44 | |
| 18 | 27.94 | 37.8 | 102. | .313E-02 | .150E+03 | .998E+02 | 0.84 | |
| 19 | 30.48 | 38.1 | 101. | .309E-02 | .148E+03 | .985E+02 | 0.13 | |
| 20 | 38.10 | 38.7 | 96. | .295E-02 | .141E+03 | .941E+02 | 0.25 | |
| 21 | 40.64 | 38.8 | 96. | .295E-02 | .141E+03 | .938E+02 | 0.03 | |
| 22 | 50.80 | 39.2 | 93. | .286E-02 | .137E+03 | .912E+02 | 0.02 | |
| 23 | 63.50 | 39.6 | 91. | .280E-02 | .134E+03 | .891E+02 | 0.01 | |
| 24 | 76.20 | 39.8 | 90. | .275E-02 | .131E+03 | .875E+02 | 0.01 | |
| 25 | 88.90 | 40.0 | 88. | .271E-02 | .130E+03 | .864E+02 | 0.03 | |

Table A.67: 1 in. cylinder with $S=1.5$ in.; $U = 27.7(m/s)$, $T = 24.5(^{\circ}C)$,
 $q = 1376(W/m^2)$, $i = 160.0(A)$

Case: 1twc-25

Date and time of experiment: Oct.11,1992, 01:30

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 38.2 | | | | | | |
| 2 | 2.54 | 38.2 | 91. | .307E-02 | .133E+03 | .886E+02 | 9.21 | |
| 3 | 3.81 | 37.6 | 101. | .342E-02 | .148E+03 | .988E+02 | 3.02 | |
| 4 | 5.08 | 36.8 | 107. | .361E-02 | .156E+03 | .104E+03 | 3.81 | |
| 5 | 6.35 | 35.8 | 123. | .416E-02 | .180E+03 | .120E+03 | 1.75 | |
| 6 | 7.62 | 34.9 | 134. | .452E-02 | .196E+03 | .131E+03 | 1.91 | |
| 7 | 8.89 | 34.1 | 147. | .496E-02 | .215E+03 | .143E+03 | 3.49 | |
| 8 | 10.16 | 33.5 | 159. | .539E-02 | .233E+03 | .156E+03 | 5.88 | |
| 9 | 11.43 | 33.3 | 161. | .545E-02 | .236E+03 | .157E+03 | 4.61 | X _{max} |
| 10 | 12.70 | 33.4 | 159. | .537E-02 | .232E+03 | .155E+03 | 4.13 | |
| 11 | 13.97 | 33.7 | 153. | .517E-02 | .224E+03 | .149E+03 | 4.13 | |
| 12 | 15.24 | 34.4 | 138. | .466E-02 | .202E+03 | .134E+03 | 0.16 | |
| 13 | 17.78 | 35.5 | 124. | .420E-02 | .182E+03 | .121E+03 | 0.69 | |
| 14 | 19.05 | 36.2 | 114. | .385E-02 | .167E+03 | .111E+03 | 2.22 | |
| 15 | 20.32 | 36.7 | 110. | .372E-02 | .161E+03 | .107E+03 | 1.43 | |
| 16 | 22.86 | 37.5 | 104. | .353E-02 | .153E+03 | .102E+03 | 0.52 | |
| 17 | 25.40 | 38.1 | 100. | .337E-02 | .146E+03 | .973E+02 | 0.44 | |
| 18 | 27.94 | 38.7 | 96. | .323E-02 | .140E+03 | .933E+02 | 0.87 | |
| 19 | 30.48 | 39.0 | 94. | .319E-02 | .138E+03 | .920E+02 | 0.13 | |
| 20 | 38.10 | 39.7 | 90. | .303E-02 | .131E+03 | .876E+02 | 0.24 | |
| 21 | 40.64 | 39.8 | 89. | .302E-02 | .131E+03 | .871E+02 | 0.03 | |
| 22 | 50.80 | 40.2 | 87. | .294E-02 | .127E+03 | .849E+02 | 0.01 | |
| 23 | 63.50 | 40.7 | 84. | .286E-02 | .124E+03 | .825E+02 | 0.02 | |
| 24 | 76.20 | 41.0 | 83. | .281E-02 | .121E+03 | .810E+02 | 0.02 | |
| 25 | 88.90 | 41.2 | 82. | .277E-02 | .120E+03 | .800E+02 | 0.03 | |

Table A.6S: 1 in. cylinder with S=1.5 in.; U = 25.1(m/s), T = 24.3(°C), q = 1383(W/m²), i = 160.0(A)

Case: 1twc-22.5

Date and time of experiment: Oct.11.1992, 03:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.2 | | | | | | |
| 2 | 2.54 | 37.3 | 83. | .312E-02 | .122E+03 | .811E+02 | 10.56 | |
| 3 | 3.81 | 36.8 | 93. | .350E-02 | .136E+03 | .909E+02 | 3.64 | |
| 4 | 5.08 | 36.1 | 98. | .368E-02 | .144E+03 | .957E+02 | 4.19 | |
| 5 | 6.35 | 35.2 | 112. | .423E-02 | .165E+03 | .110E+03 | 1.28 | |
| 6 | 7.62 | 34.3 | 123. | .461E-02 | .180E+03 | .120E+03 | 1.64 | |
| 7 | 8.89 | 33.5 | 136. | .510E-02 | .199E+03 | .133E+03 | 3.83 | |
| 8 | 10.16 | 33.0 | 148. | .556E-02 | .217E+03 | .145E+03 | 6.38 | |
| 9 | 11.43 | 32.8 | 149. | .560E-02 | .218E+03 | .146E+03 | 4.55 | X_{max} |
| 10 | 12.70 | 32.8 | 148. | .558E-02 | .217E+03 | .145E+03 | 4.55 | |
| 11 | 13.97 | 33.1 | 144. | .540E-02 | .211E+03 | .140E+03 | 4.74 | |
| 12 | 15.24 | 33.6 | 129. | .486E-02 | .189E+03 | .126E+03 | 0.12 | |
| 13 | 17.78 | 34.8 | 116. | .437E-02 | .170E+03 | .114E+03 | 0.85 | |
| 14 | 19.05 | 35.4 | 106. | .399E-02 | .156E+03 | .104E+03 | 2.37 | |
| 15 | 20.32 | 35.9 | 103. | .386E-02 | .150E+03 | .100E+03 | 1.40 | |
| 16 | 22.86 | 36.7 | 97. | .364E-02 | .142E+03 | .947E+02 | 0.64 | |
| 17 | 25.40 | 37.3 | 92. | .348E-02 | .135E+03 | .903E+02 | 0.41 | |
| 18 | 27.94 | 37.8 | 88. | .331E-02 | .129E+03 | .861E+02 | 1.09 | |
| 19 | 30.48 | 38.1 | 87. | .327E-02 | .128E+03 | .850E+02 | 0.14 | |
| 20 | 38.10 | 38.9 | 83. | .311E-02 | .121E+03 | .808E+02 | 0.27 | |
| 21 | 40.64 | 39.0 | 82. | .309E-02 | .120E+03 | .803E+02 | 0.03 | |
| 22 | 50.80 | 39.4 | 80. | .301E-02 | .117E+03 | .781E+02 | 0.02 | |
| 23 | 63.50 | 39.8 | 78. | .293E-02 | .114E+03 | .762E+02 | 0.02 | |
| 24 | 76.20 | 40.0 | 77. | .288E-02 | .112E+03 | .749E+02 | 0.02 | |
| 25 | 88.90 | 40.2 | 76. | .285E-02 | .111E+03 | .741E+02 | 0.03 | |

Table A.69: 1 in. cylinder with $S=1.5$ in.; $U = 22.6(m/s)$, $T = 24.3(^{\circ}C)$, $q = 1206(W/m^2)$, $i = 150.0(A)$

Case: 1twc-20

Date and time of experiment: Oct.11,1992, 02:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------------|
| 1 | 1.27 | 38.4 | | | | | | |
| 2 | 2.54 | 38.4 | 75. | .319E-02 | .110E+03 | .734E+02 | 11.27 | |
| 3 | 3.81 | 37.9 | 84. | .359E-02 | .124E+03 | .825E+02 | 4.18 | |
| 4 | 5.08 | 37.1 | 90. | .382E-02 | .132E+03 | .878E+02 | 4.00 | |
| 5 | 6.35 | 36.1 | 103. | .438E-02 | .151E+03 | .101E+03 | 1.45 | |
| 6 | 7.62 | 35.1 | 112. | .477E-02 | .165E+03 | .110E+03 | 1.82 | |
| 7 | 8.89 | 34.3 | 124. | .527E-02 | .182E+03 | .121E+03 | 3.82 | |
| 8 | 10.16 | 33.6 | 136. | .579E-02 | .200E+03 | .133E+03 | 6.91 | |
| 9 | 11.43 | 33.4 | 138. | .587E-02 | .202E+03 | .135E+03 | 5.45 | λ_{max} |
| 10 | 12.70 | 33.4 | 137. | .581E-02 | .201E+03 | .134E+03 | 5.09 | |
| 11 | 13.97 | 33.8 | 132. | .559E-02 | .193E+03 | .129E+03 | 4.72 | |
| 12 | 15.24 | 34.4 | 119. | .505E-02 | .174E+03 | .116E+03 | 0.24 | |
| 13 | 17.78 | 35.6 | 106. | .452E-02 | .156E+03 | .104E+03 | 0.61 | |
| 14 | 19.05 | 36.3 | 98. | .418E-02 | .144E+03 | .961E+02 | 1.64 | |
| 15 | 20.32 | 36.8 | 94. | .400E-02 | .138E+03 | .920E+02 | 1.45 | |
| 16 | 22.86 | 37.7 | 88. | .376E-02 | .130E+03 | .864E+02 | 0.82 | |
| 17 | 25.40 | 38.4 | 84. | .358E-02 | .124E+03 | .824E+02 | 0.41 | |
| 18 | 27.94 | 39.1 | 80. | .341E-02 | .118E+03 | .783E+02 | 1.14 | |
| 19 | 30.48 | 39.4 | 79. | .335E-02 | .116E+03 | .771E+02 | 0.23 | |
| 20 | 38.10 | 40.3 | 75. | .318E-02 | .110E+03 | .730E+02 | 0.30 | |
| 21 | 40.64 | 40.4 | 74. | .315E-02 | .109E+03 | .725E+02 | 0.04 | |
| 22 | 50.80 | 40.9 | 72. | .306E-02 | .105E+03 | .703E+02 | 0.04 | |
| 23 | 63.50 | 41.4 | 70. | .298E-02 | .103E+03 | .686E+02 | 0.04 | |
| 24 | 76.20 | 41.6 | 69. | .295E-02 | .102E+03 | .678E+02 | 0.02 | |
| 25 | 88.90 | 41.7 | 69. | .293E-02 | .101E+03 | .673E+02 | 0.02 | |

Table A.70: 1 in. cylinder with $S=1.5$ in.; $U = 20.0(m/s)$, $T = 24.2(^{\circ}C)$, $q = 1209(W/m^2)$, $i = 150.0(A)$

Case: 1twc-17.5

Date and time of experiment: Oct.11,1992, 02:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.7 | | | | | | |
| 2 | 2.54 | 37.8 | 68. | .326E-02 | .996E+02 | .664E+02 | 11.47 | |
| 3 | 3.81 | 37.3 | 75. | .362E-02 | .111E+03 | .737E+02 | 5.21 | |
| 4 | 5.08 | 36.6 | 81. | .388E-02 | .118E+03 | .789E+02 | 4.17 | |
| 5 | 6.35 | 35.6 | 92. | .441E-02 | .135E+03 | .898E+02 | 0.83 | |
| 6 | 7.62 | 34.7 | 101. | .484E-02 | .148E+03 | .986E+02 | 2.08 | |
| 7 | 8.89 | 33.9 | 111. | .533E-02 | .163E+03 | .109E+03 | 3.96 | |
| 8 | 10.16 | 33.3 | 121. | .580E-02 | .177E+03 | .118E+03 | 6.04 | |
| 9 | 11.43 | 33.0 | 127. | .609E-02 | .186E+03 | .124E+03 | 7.50 | X_{max} |
| 10 | 12.70 | 33.0 | 122. | .584E-02 | .178E+03 | .119E+03 | 3.54 | |
| 11 | 13.97 | 33.3 | 122. | .588E-02 | .179E+03 | .120E+03 | 6.67 | |
| 12 | 15.24 | 33.8 | 109. | .525E-02 | .160E+03 | .107E+03 | 0.76 | |
| 13 | 17.78 | 34.9 | 98. | .469E-02 | .143E+03 | .955E+02 | 0.90 | |
| 14 | 19.05 | 35.6 | 89. | .428E-02 | .131E+03 | .870E+02 | 2.50 | |
| 15 | 20.32 | 36.1 | 86. | .414E-02 | .127E+03 | .843E+02 | 1.18 | |
| 16 | 22.86 | 37.0 | 81. | .387E-02 | .118E+03 | .787E+02 | 0.94 | |
| 17 | 25.40 | 37.7 | 77. | .369E-02 | .113E+03 | .751E+02 | 0.36 | |
| 18 | 27.94 | 38.4 | 73. | .349E-02 | .107E+03 | .711E+02 | 1.25 | |
| 19 | 30.48 | 38.8 | 71. | .343E-02 | .105E+03 | .698E+02 | 0.29 | |
| 20 | 38.10 | 39.6 | 67. | .324E-02 | .988E+02 | .659E+02 | 0.34 | |
| 21 | 40.64 | 39.8 | 67. | .321E-02 | .981E+02 | .654E+02 | 0.07 | |
| 22 | 50.80 | 40.3 | 65. | .311E-02 | .950E+02 | .633E+02 | 0.05 | |
| 23 | 63.50 | 40.7 | 63. | .304E-02 | .927E+02 | .618E+02 | 0.04 | |
| 24 | 76.20 | 40.9 | 63. | .300E-02 | .916E+02 | .611E+02 | 0.03 | |
| 25 | 88.90 | 41.0 | 62. | .299E-02 | .912E+02 | .608E+02 | 0.02 | |

Table A.71: 1 in. cylinder with $S=1.5$ in.; $U = 17.7(m/s)$, $T = 24.1(^{\circ}C)$, $q = 1054(W/m^2)$, $i = 140.0(A)$

Case: 1twc-15a

Date and time of experiment: Oct.11,1992, 00:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 34.9 | | | | | | |
| 2 | 2.54 | 35.7 | 60. | .341E-02 | .883E+02 | .589E+02 | 19.99 | |
| 3 | 3.81 | 35.7 | 68. | .387E-02 | .100E+03 | .667E+02 | 9.63 | |
| 4 | 5.08 | 35.3 | 73. | .415E-02 | .107E+03 | .716E+02 | 6.50 | |
| 5 | 6.35 | 34.5 | 82. | .462E-02 | .119E+03 | .796E+02 | 2.41 | |
| 6 | 7.62 | 33.7 | 92. | .518E-02 | .134E+03 | .894E+02 | 1.44 | |
| 7 | 8.89 | 33.0 | 101. | .573E-02 | .148E+03 | .989E+02 | 3.85 | |
| 8 | 10.16 | 32.4 | 111. | .632E-02 | .163E+03 | .109E+03 | 7.22 | |
| 9 | 11.43 | 32.1 | 115. | .652E-02 | .169E+03 | .112E+03 | 6.98 | X_{mar} |
| 10 | 12.70 | 32.1 | 113. | .640E-02 | .166E+03 | .110E+03 | 5.06 | |
| 11 | 13.97 | 32.3 | 112. | .632E-02 | .163E+03 | .109E+03 | 6.26 | |
| 12 | 15.24 | 32.8 | 101. | .571E-02 | .148E+03 | .985E+02 | 1.28 | |
| 13 | 17.78 | 33.9 | 89. | .505E-02 | .131E+03 | .871E+02 | 0.32 | |
| 14 | 19.05 | 34.4 | 82. | .463E-02 | .120E+03 | .799E+02 | 2.89 | |
| 15 | 20.32 | 34.9 | 81. | .458E-02 | .118E+03 | .790E+02 | 0.00 | |
| 16 | 22.86 | 35.8 | 74. | .419E-02 | .108E+03 | .723E+02 | 1.20 | |
| 17 | 25.40 | 36.5 | 70. | .399E-02 | .103E+03 | .688E+02 | 0.54 | |
| 18 | 27.94 | 37.1 | 67. | .378E-02 | .979E+02 | .652E+02 | 1.20 | |
| 19 | 30.48 | 37.5 | 65. | .370E-02 | .957E+02 | .638E+02 | 0.45 | |
| 20 | 36.10 | 38.3 | 62. | .351E-02 | .908E+02 | .606E+02 | 0.21 | |
| 21 | 40.64 | 38.5 | 61. | .347E-02 | .897E+02 | .598E+02 | 0.16 | |
| 22 | 50.80 | 39.0 | 59. | .336E-02 | .870E+02 | .580E+02 | 0.04 | |
| 23 | 63.50 | 39.4 | 58. | .326E-02 | .844E+02 | .563E+02 | 0.04 | |
| 24 | 76.20 | 39.8 | 57. | .320E-02 | .828E+02 | .552E+02 | 0.05 | |
| 25 | 88.90 | 39.9 | 56. | .318E-02 | .823E+02 | .549E+02 | 0.02 | |

Table A.72: 1 in. cylinder with $S=1.5$ in.; $U = 15.0(m/s)$, $T = 23.6(^{\circ}C)$, $q = 912(W/m^2)$, $i = 130.0(A)$

Case: 1twc-15b

Date and time of experiment: Oct.11,1992, 04:00

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 37.5 | | | | | | |
| 2 | 2.54 | 37.6 | 57. | .322E-02 | .839E+02 | .559E+02 | 14.43 | |
| 3 | 3.81 | 37.2 | 66. | .369E-02 | .962E+02 | .641E+02 | 5.05 | |
| 4 | 5.08 | 36.5 | 72. | .403E-02 | .105E+03 | .700E+02 | 1.44 | |
| 5 | 6.35 | 35.8 | 74. | .418E-02 | .109E+03 | .726E+02 | 3.61 | |
| 6 | 7.62 | 35.0 | 83. | .469E-02 | .122E+03 | .814E+02 | 0.24 | |
| 7 | 8.89 | 34.1 | 94. | .531E-02 | .138E+03 | .922E+02 | 4.81 | |
| 8 | 10.16 | 33.5 | 102. | .574E-02 | .149E+03 | .997E+02 | 6.01 | |
| 9 | 11.43 | 33.1 | 111. | .625E-02 | .163E+03 | .109E+03 | 10.58 | X _{max} |
| 10 | 12.70 | 33.1 | 106. | .598E-02 | .156E+03 | .104E+03 | 6.25 | |
| 11 | 13.97 | 33.4 | 102. | .574E-02 | .149E+03 | .996E+02 | 5.29 | |
| 12 | 15.24 | 33.9 | 91. | .513E-02 | .134E+03 | .890E+02 | 0.72 | |
| 13 | 17.78 | 34.9 | 86. | .484E-02 | .126E+03 | .840E+02 | 2.65 | |
| 14 | 19.05 | 35.5 | 77. | .432E-02 | .113E+03 | .751E+02 | 2.89 | |
| 15 | 20.32 | 36.0 | 74. | .418E-02 | .109E+03 | .725E+02 | 2.00 | |
| 16 | 22.86 | 36.8 | 71. | .399E-02 | .104E+03 | .693E+02 | 0.12 | |
| 17 | 25.40 | 37.6 | 67. | .375E-02 | .976E+02 | .651E+02 | 0.66 | |
| 18 | 27.94 | 38.3 | 63. | .354E-02 | .922E+02 | .615E+02 | 1.62 | |
| 19 | 30.48 | 38.6 | 62. | .349E-02 | .910E+02 | .607E+02 | 0.22 | |
| 20 | 38.10 | 39.6 | 58. | .328E-02 | .854E+02 | .569E+02 | 0.32 | |
| 21 | 40.64 | 39.8 | 58. | .324E-02 | .844E+02 | .562E+02 | 0.20 | |
| 22 | 50.80 | 40.3 | 56. | .315E-02 | .819E+02 | .546E+02 | 0.05 | |
| 23 | 63.50 | 40.8 | 54. | .306E-02 | .797E+02 | .531E+02 | 0.08 | |
| 24 | 76.20 | 40.9 | 54. | .304E-02 | .792E+02 | .528E+02 | 0.03 | |
| 25 | 88.90 | 40.9 | 54. | .304E-02 | .791E+02 | .528E+02 | 0.00 | |

Table A.73: 1 in. cylinder with S=1.5 in.; $U = 15.1(m/s)$, $T = 24.0(^{\circ}C)$, $q = 913(W/m^2)$, $i = 130.0(A)$

Case: 1twc-12.5

Date and time of experiment: Oct.11,1992, 05:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.2 | | | | | | |
| 2 | 2.54 | 36.4 | 50. | .342E-02 | .737E+02 | .492E+02 | 16.26 | |
| 3 | 3.81 | 36.1 | 57. | .386E-02 | .832E+02 | .555E+02 | 7.70 | |
| 4 | 5.08 | 35.6 | 61. | .414E-02 | .893E+02 | .596E+02 | 5.42 | |
| 5 | 6.35 | 34.8 | 67. | .458E-02 | .989E+02 | .659E+02 | 2.00 | |
| 6 | 7.62 | 34.0 | 75. | .511E-02 | .110E+03 | .735E+02 | 1.14 | |
| 7 | 8.89 | 33.2 | 84. | .572E-02 | .123E+03 | .823E+02 | 4.56 | |
| 8 | 10.16 | 32.6 | 93. | .629E-02 | .136E+03 | .905E+02 | 7.42 | |
| 9 | 11.43 | 32.2 | 96. | .654E-02 | .141E+03 | .941E+02 | 7.13 | |
| 10 | 12.70 | 32.1 | 97. | .662E-02 | .143E+03 | .952E+02 | 6.85 | X_{max} |
| 11 | 13.97 | 32.2 | 97. | .660E-02 | .142E+03 | .949E+02 | 7.99 | |
| 12 | 15.24 | 32.6 | 88. | .600E-02 | .129E+03 | .863E+02 | 2.85 | |
| 13 | 17.78 | 33.7 | 77. | .524E-02 | .113E+03 | .753E+02 | 0.76 | |
| 14 | 19.05 | 34.3 | 70. | .477E-02 | .103E+03 | .686E+02 | 2.85 | |
| 15 | 20.32 | 34.8 | 68. | .464E-02 | .100E+03 | .667E+02 | 1.14 | |
| 16 | 22.86 | 35.6 | 63. | .431E-02 | .930E+02 | .620E+02 | 1.07 | |
| 17 | 25.40 | 36.3 | 60. | .410E-02 | .885E+02 | .590E+02 | 0.29 | |
| 18 | 27.94 | 37.0 | 57. | .385E-02 | .830E+02 | .553E+02 | 1.57 | |
| 19 | 30.48 | 37.5 | 55. | .376E-02 | .812E+02 | .541E+02 | 0.44 | |
| 20 | 38.10 | 38.4 | 52. | .352E-02 | .758E+02 | .505E+02 | 0.45 | |
| 21 | 40.64 | 38.6 | 51. | .348E-02 | .750E+02 | .500E+02 | 0.17 | |
| 22 | 50.80 | 39.2 | 49. | .336E-02 | .724E+02 | .483E+02 | 0.09 | |
| 23 | 63.50 | 39.6 | 48. | .327E-02 | .705E+02 | .470E+02 | 0.07 | |
| 24 | 76.20 | 39.8 | 48. | .324E-02 | .699E+02 | .466E+02 | 0.05 | |
| 25 | 88.90 | 39.7 | 48. | .325E-02 | .700E+02 | .467E+02 | 0.01 | |

Table A.74: 1 in. cylinder with $S=1.5$ in.; $U = 12.4(m/s)$, $T = 23.6(^{\circ}C)$, $q = 770(W/m^2)$, $i = 120.0(A)$

Case: 1twc-10

Date and time of experiment: Oct.11,1992, 05:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.1 | | | | | | |
| 2 | 2.54 | 36.4 | 42. | .355E-02 | .611E+02 | .408E+02 | 18.54 | |
| 3 | 3.81 | 36.1 | 48. | .405E-02 | .697E+02 | .465E+02 | 9.10 | |
| 4 | 5.08 | 35.6 | 52. | .439E-02 | .756E+02 | .504E+02 | 5.73 | |
| 5 | 6.35 | 34.9 | 57. | .482E-02 | .829E+02 | .553E+02 | 2.70 | |
| 6 | 7.62 | 34.1 | 63. | .532E-02 | .917E+02 | .611E+02 | 0.00 | |
| 7 | 8.89 | 33.3 | 72. | .611E-02 | .105E+03 | .702E+02 | 6.07 | |
| 8 | 10.16 | 32.7 | 78. | .665E-02 | .115E+03 | .763E+02 | 8.09 | |
| 9 | 11.43 | 32.3 | 81. | .689E-02 | .119E+03 | .791E+02 | 7.42 | |
| 10 | 12.70 | 32.2 | 83. | .708E-02 | .122E+03 | .813E+02 | 8.43 | X_{max} |
| 11 | 13.97 | 32.3 | 82. | .702E-02 | .121E+03 | .806E+02 | 8.77 | |
| 12 | 15.24 | 32.6 | 75. | .638E-02 | .110E+03 | .733E+02 | 3.03 | |
| 13 | 17.78 | 33.6 | 66. | .566E-02 | .974E+02 | .650E+02 | 1.46 | |
| 14 | 19.05 | 34.2 | 61. | .515E-02 | .888E+02 | .592E+02 | 2.36 | |
| 15 | 20.32 | 34.7 | 59. | .499E-02 | .860E+02 | .573E+02 | 1.01 | |
| 16 | 22.86 | 35.6 | 54. | .461E-02 | .794E+02 | .529E+02 | 1.18 | |
| 17 | 25.40 | 36.3 | 51. | .437E-02 | .753E+02 | .502E+02 | 0.42 | |
| 18 | 27.94 | 37.0 | 48. | .408E-02 | .703E+02 | .469E+02 | 1.77 | |
| 19 | 30.48 | 37.5 | 47. | .399E-02 | .687E+02 | .458E+02 | 0.58 | |
| 20 | 38.10 | 38.6 | 44. | .371E-02 | .638E+02 | .426E+02 | 0.48 | |
| 21 | 40.64 | 38.8 | 43. | .366E-02 | .630E+02 | .420E+02 | 0.27 | |
| 22 | 50.80 | 39.4 | 41. | .351E-02 | .605E+02 | .403E+02 | 0.13 | |
| 23 | 63.50 | 39.9 | 40. | .342E-02 | .589E+02 | .392E+02 | 0.09 | |
| 24 | 76.20 | 40.0 | 40. | .339E-02 | .583E+02 | .389E+02 | 0.09 | |
| 25 | 88.90 | 39.9 | 40. | .341E-02 | .587E+02 | .392E+02 | 0.03 | |

Table A.75: 1 in. cylinder with $S=1.5$ in.; $U = 9.9(m/s)$, $T = 23.7(^{\circ}C)$,
 $q = 651(W/m^2)$, $i = 110.0(A)$

Case: 1twc-8.7

Date and time of experiment: Oct.11,1992, 05:00

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.4 | | | | | | |
| 2 | 2.54 | 36.8 | 39. | .386E-02 | .577E+02 | .385E+02 | 19.52 | |
| 3 | 3.81 | 36.7 | 44. | .429E-02 | .642E+02 | .428E+02 | 11.30 | |
| 4 | 5.08 | 36.2 | 47. | .461E-02 | .689E+02 | .459E+02 | 8.22 | |
| 5 | 6.35 | 35.5 | 52. | .510E-02 | .762E+02 | .508E+02 | 4.11 | |
| 6 | 7.62 | 34.7 | 58. | .571E-02 | .854E+02 | .570E+02 | 0.00 | |
| 7 | 8.89 | 33.9 | 66. | .649E-02 | .971E+02 | .647E+02 | 5.14 | |
| 8 | 10.16 | 33.2 | 73. | .717E-02 | .107E+03 | .715E+02 | 8.56 | |
| 9 | 11.43 | 32.8 | 76. | .743E-02 | .111E+03 | .741E+02 | 7.53 | |
| 10 | 12.70 | 32.6 | 80. | .779E-02 | .117E+03 | .777E+02 | 10.27 | X_{max} |
| 11 | 13.97 | 32.7 | 76. | .744E-02 | .111E+03 | .742E+02 | 6.51 | |
| 12 | 15.24 | 33.0 | 72. | .709E-02 | .106E+03 | .707E+02 | 4.79 | |
| 13 | 17.78 | 34.0 | 63. | .621E-02 | .929E+02 | .619E+02 | 1.60 | |
| 14 | 19.05 | 34.6 | 58. | .565E-02 | .845E+02 | .564E+02 | 2.40 | |
| 15 | 20.32 | 35.1 | 56. | .551E-02 | .824E+02 | .549E+02 | 0.46 | |
| 16 | 22.86 | 36.0 | 51. | .504E-02 | .754E+02 | .502E+02 | 1.28 | |
| 17 | 25.40 | 36.8 | 49. | .476E-02 | .713E+02 | .475E+02 | 0.51 | |
| 18 | 27.94 | 37.6 | 45. | .445E-02 | .666E+02 | .444E+02 | 1.71 | |
| 19 | 30.48 | 38.1 | 44. | .433E-02 | .647E+02 | .431E+02 | 0.68 | |
| 20 | 38.10 | 39.3 | 41. | .401E-02 | .600E+02 | .400E+02 | 0.47 | |
| 21 | 40.64 | 39.6 | 40. | .394E-02 | .590E+02 | .393E+02 | 0.34 | |
| 22 | 50.80 | 40.3 | 39. | .378E-02 | .566E+02 | .377E+02 | 0.15 | |
| 23 | 63.50 | 40.8 | 37. | .367E-02 | .549E+02 | .366E+02 | 0.11 | |
| 24 | 76.20 | 41.0 | 37. | .363E-02 | .543E+02 | .362E+02 | 0.13 | |
| 25 | 88.90 | 40.8 | 38. | .368E-02 | .551E+02 | .367E+02 | 0.07 | |

Table A.76: 1 in. cylinder with $S=1.5$ in.; $U = 8.6(m/s)$, $T = 23.7(^{\circ}C)$, $q = 641(W/m^2)$, $i = 110.0(A)$

Case: Itwc-7.5a

Date and time of experiment: Oct.11,1992, 04:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.3 | | | | | | |
| 2 | 2.54 | 36.6 | 34. | .386E-02 | .504E+02 | .336E+02 | 18.97 | |
| 3 | 3.81 | 36.4 | 38. | .427E-02 | .557E+02 | .371E+02 | 11.70 | |
| 4 | 5.08 | 35.9 | 40. | .453E-02 | .591E+02 | .394E+02 | 9.69 | |
| 5 | 6.35 | 35.2 | 46. | .517E-02 | .675E+02 | .450E+02 | 2.83 | |
| 6 | 7.62 | 34.5 | 51. | .568E-02 | .741E+02 | .494E+02 | 0.40 | |
| 7 | 8.89 | 33.7 | 57. | .645E-02 | .841E+02 | .561E+02 | 4.84 | |
| 8 | 10.16 | 33.0 | 64. | .720E-02 | .939E+02 | .626E+02 | 9.28 | |
| 9 | 11.43 | 32.6 | 67. | .755E-02 | .985E+02 | .657E+02 | 9.28 | |
| 10 | 12.70 | 32.4 | 69. | .775E-02 | .101E+03 | .674E+02 | 9.69 | X_{max} |
| 11 | 13.97 | 32.4 | 69. | .774E-02 | .101E+03 | .674E+02 | 10.09 | |
| 12 | 15.24 | 32.7 | 63. | .710E-02 | .926E+02 | .618E+02 | 4.30 | |
| 13 | 17.78 | 33.6 | 56. | .634E-02 | .827E+02 | .551E+02 | 2.42 | |
| 14 | 19.05 | 34.2 | 51. | .575E-02 | .750E+02 | .500E+02 | 2.02 | |
| 15 | 20.32 | 34.7 | 49. | .556E-02 | .725E+02 | .483E+02 | 0.81 | |
| 16 | 22.86 | 35.6 | 45. | .510E-02 | .665E+02 | .444E+02 | 1.31 | |
| 17 | 25.40 | 36.4 | 43. | .483E-02 | .630E+02 | .420E+02 | 0.30 | |
| 18 | 27.94 | 37.1 | 40. | .447E-02 | .583E+02 | .389E+02 | 2.12 | |
| 19 | 30.48 | 37.7 | 39. | .436E-02 | .568E+02 | .379E+02 | 0.76 | |
| 20 | 38.10 | 38.9 | 36. | .402E-02 | .524E+02 | .350E+02 | 0.50 | |
| 21 | 40.64 | 39.2 | 35. | .394E-02 | .514E+02 | .343E+02 | 0.47 | |
| 22 | 50.80 | 39.9 | 34. | .378E-02 | .493E+02 | .328E+02 | 0.18 | |
| 23 | 63.50 | 40.4 | 33. | .366E-02 | .478E+02 | .319E+02 | 0.13 | |
| 24 | 76.20 | 40.6 | 32. | .362E-02 | .472E+02 | .315E+02 | 0.19 | |
| 25 | 88.90 | 40.3 | 33. | .369E-02 | .482E+02 | .321E+02 | 0.12 | |

Table A.77: 1 in. cylinder with $S=1.5$ in.; $U = 7.5(m/s)$, $T = 23.8(^{\circ}C)$,
 $q = 544(W/m^2)$, $i = 100.0(A)$

Case: 1twc-7.5b

Date and time of experiment: Oct.11,1992, 06:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|--------------|
| 1 | 1.27 | 35.4 | | | | | | |
| 2 | 2.54 | 35.9 | 34. | .378E-02 | .493E+02 | .328E+02 | 21.56 | |
| 3 | 3.81 | 35.8 | 37. | .421E-02 | .549E+02 | .366E+02 | 13.27 | |
| 4 | 5.08 | 35.4 | 40. | .454E-02 | .592E+02 | .395E+02 | 9.54 | |
| 5 | 6.35 | 34.7 | 45. | .508E-02 | .663E+02 | .442E+02 | 4.15 | |
| 6 | 7.62 | 34.0 | 50. | .561E-02 | .731E+02 | .488E+02 | 1.24 | |
| 7 | 8.89 | 33.2 | 58. | .648E-02 | .846E+02 | .564E+02 | 5.80 | |
| 8 | 10.16 | 32.6 | 64. | .723E-02 | .943E+02 | .629E+02 | 10.37 | |
| 9 | 11.43 | 32.2 | 65. | .735E-02 | .959E+02 | .639E+02 | 7.46 | |
| 10 | 12.70 | 32.0 | 67. | .758E-02 | .989E+02 | .659E+02 | 8.29 | |
| 11 | 13.97 | 32.0 | 68. | .764E-02 | .996E+02 | .664E+02 | 9.12 | χ_{max} |
| 12 | 15.24 | 32.2 | 64. | .723E-02 | .943E+02 | .629E+02 | 5.94 | |
| 13 | 17.78 | 33.1 | 57. | .635E-02 | .828E+02 | .552E+02 | 2.35 | |
| 14 | 19.05 | 33.6 | 51. | .574E-02 | .749E+02 | .499E+02 | 2.49 | |
| 15 | 20.32 | 34.1 | 50. | .561E-02 | .732E+02 | .488E+02 | 0.28 | |
| 16 | 22.86 | 35.0 | 46. | .511E-02 | .667E+02 | .445E+02 | 1.45 | |
| 17 | 25.40 | 35.7 | 43. | .485E-02 | .633E+02 | .422E+02 | 0.31 | |
| 18 | 27.94 | 36.5 | 40. | .450E-02 | .586E+02 | .391E+02 | 2.07 | |
| 19 | 30.48 | 37.0 | 39. | .438E-02 | .571E+02 | .381E+02 | 0.74 | |
| 20 | 38.10 | 38.1 | 36. | .404E-02 | .527E+02 | .351E+02 | 0.60 | |
| 21 | 40.64 | 38.4 | 35. | .397E-02 | .519E+02 | .346E+02 | 0.33 | |
| 22 | 50.80 | 39.2 | 34. | .379E-02 | .494E+02 | .329E+02 | 0.22 | |
| 23 | 63.50 | 39.6 | 33. | .368E-02 | .480E+02 | .320E+02 | 0.13 | |
| 24 | 76.20 | 39.8 | 32. | .364E-02 | .475E+02 | .317E+02 | 0.18 | |
| 25 | 88.90 | 39.5 | 33. | .372E-02 | .485E+02 | .323E+02 | 0.12 | |

Table A.7S: 1 in. cylinder with $S=1.5$ in.; $U = 7.5(m/s)$, $T = 23.5(^{\circ}C)$, $q = 530(W/m^2)$, $i = 100.0(A)$

Case: 1twc-06

Date and time of experiment: Oct.11,199~96:00

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.5 | | | | | | |
| 2 | 2.54 | 35.8 | 28. | .406E-02 | .409E+02 | .273E+02 | 20.34 | |
| 3 | 3.81 | 35.6 | 31. | .450E-02 | .454E+02 | .302E+02 | 12.71 | |
| 4 | 5.08 | 35.2 | 32. | .464E-02 | .469E+02 | .312E+02 | 12.71 | |
| 5 | 6.35 | 34.6 | 37. | .537E-02 | .542E+02 | .361E+02 | 4.58 | |
| 6 | 7.62 | 33.9 | 41. | .596E-02 | .601E+02 | .401E+02 | 1.02 | |
| 7 | 8.89 | 33.1 | 47. | .685E-02 | .691E+02 | .461E+02 | 5.59 | |
| 8 | 10.16 | 32.5 | 52. | .762E-02 | .769E+02 | .512E+02 | 9.66 | |
| 9 | 11.43 | 32.0 | 55. | .802E-02 | .809E+02 | .539E+02 | 9.66 | |
| 10 | 12.70 | 31.8 | 57. | .835E-02 | .842E+02 | .561E+02 | 10.68 | |
| 11 | 13.97 | 31.7 | 59. | .863E-02 | .870E+02 | .580E+02 | 13.73 | X_{mar} |
| 12 | 15.24 | 31.9 | 54. | .784E-02 | .791E+02 | .527E+02 | 6.10 | |
| 13 | 17.78 | 32.7 | 48. | .696E-02 | .702E+02 | .468E+02 | 3.05 | |
| 14 | 19.05 | 33.2 | 43. | .628E-02 | .634E+02 | .423E+02 | 2.03 | |
| 15 | 20.32 | 33.7 | 42. | .609E-02 | .615E+02 | .410E+02 | 0.68 | |
| 16 | 22.86 | 34.5 | 39. | .559E-02 | .564E+02 | .376E+02 | 1.14 | |
| 17 | 25.40 | 35.3 | 36. | .528E-02 | .533E+02 | .355E+02 | 0.13 | |
| 18 | 27.94 | 36.1 | 33. | .485E-02 | .489E+02 | .326E+02 | 2.41 | |
| 19 | 30.48 | 36.6 | 32. | .472E-02 | .476E+02 | .317E+02 | 0.83 | |
| 20 | 38.10 | 37.9 | 30. | .429E-02 | .433E+02 | .289E+02 | 0.76 | |
| 21 | 40.64 | 38.3 | 29. | .421E-02 | .425E+02 | .283E+02 | 0.48 | |
| 22 | 50.80 | 39.2 | 27. | .398E-02 | .401E+02 | .267E+02 | 0.32 | |
| 23 | 63.50 | 39.7 | 26. | .384E-02 | .388E+02 | .259E+02 | 0.22 | |
| 24 | 76.20 | 39.8 | 26. | .382E-02 | .385E+02 | .257E+02 | 0.29 | |
| 25 | 88.90 | 39.4 | 27. | .395E-02 | .398E+02 | .266E+02 | 0.23 | |

Table A.79: 1 in. cylinder with $S=1.5$ in.; $U = 5.8(m/s)$, $T = 23.4(^{\circ}C)$,
 $q = 432(W/m^2)$, $i = 90.0(A)$

Case: 1twc-05

Date and time of experiment: Oct.11,1992, 04:45

| No. | X(cm) | T(°C) | h | St | $\frac{h}{D} Pr_s$ | Nu_d | cond% | |
|-----|-------|-------|-----|----------|--------------------|----------|-------|-----------|
| 1 | 1.27 | 36.0 | | | | | | |
| 2 | 2.54 | 36.4 | 26. | .439E-02 | .382E+02 | .255E+02 | 22.23 | |
| 3 | 3.81 | 36.4 | 28. | .476E-02 | .414E+02 | .276E+02 | 15.66 | |
| 4 | 5.08 | 36.1 | 29. | .485E-02 | .422E+02 | .281E+02 | 16.17 | |
| 5 | 6.35 | 35.5 | 34. | .572E-02 | .497E+02 | .332E+02 | 6.06 | |
| 6 | 7.62 | 34.8 | 38. | .643E-02 | .559E+02 | .373E+02 | 1.01 | |
| 7 | 8.89 | 34.0 | 44. | .743E-02 | .646E+02 | .431E+02 | 6.57 | |
| 8 | 10.16 | 33.3 | 48. | .810E-02 | .704E+02 | .469E+02 | 9.09 | |
| 9 | 11.43 | 32.9 | 51. | .861E-02 | .749E+02 | .499E+02 | 10.61 | |
| 10 | 12.70 | 32.6 | 53. | .889E-02 | .773E+02 | .515E+02 | 11.11 | |
| 11 | 13.97 | 32.6 | 54. | .908E-02 | .789E+02 | .526E+02 | 13.13 | X_{max} |
| 12 | 15.24 | 32.8 | 49. | .826E-02 | .718E+02 | .479E+02 | 5.56 | |
| 13 | 17.78 | 33.6 | 44. | .750E-02 | .652E+02 | .435E+02 | 3.87 | |
| 14 | 19.05 | 34.1 | 40. | .673E-02 | .586E+02 | .390E+02 | 2.02 | |
| 15 | 20.32 | 34.6 | 39. | .655E-02 | .570E+02 | .380E+02 | 0.51 | |
| 16 | 22.86 | 35.5 | 36. | .601E-02 | .522E+02 | .348E+02 | 1.26 | |
| 17 | 25.40 | 36.3 | 34. | .569E-02 | .495E+02 | .330E+02 | 0.25 | |
| 18 | 27.94 | 37.1 | 31. | .525E-02 | .456E+02 | .304E+02 | 2.27 | |
| 19 | 30.48 | 37.7 | 30. | .510E-02 | .443E+02 | .296E+02 | 0.84 | |
| 20 | 38.10 | 39.1 | 28. | .464E-02 | .404E+02 | .269E+02 | 0.67 | |
| 21 | 40.64 | 39.5 | 27. | .453E-02 | .394E+02 | .263E+02 | 0.72 | |
| 22 | 50.80 | 40.4 | 26. | .431E-02 | .375E+02 | .250E+02 | 0.28 | |
| 23 | 63.50 | 41.1 | 25. | .415E-02 | .361E+02 | .241E+02 | 0.26 | |
| 24 | 76.20 | 41.2 | 24. | .412E-02 | .359E+02 | .239E+02 | 0.31 | |
| 25 | 88.90 | 40.7 | 25. | .426E-02 | .371E+02 | .247E+02 | 0.25 | |

Table A.80: 1 in. cylinder with $S=1.5$ in.; $U = 5.0(m/s)$, $T = 23.5(^{\circ}C)$,
 $q = 435(W/m^2)$, $i = 90.0(A)$

A.a-vi Data and Results for 1" cylinder in Different
Velocities; $S = 2''$

Case: 1twd-30a

Date and time of experiment: Oct.17,1992, 23:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.7 | | | | | | |
| 2 | 2.54 | 37.1 | 98. | .276E-02 | .204E+03 | .961E+02 | 9.64 | |
| 3 | 3.81 | 36.8 | 108. | .304E-02 | .225E+03 | .106E+03 | 2.69 | |
| 4 | 5.08 | 36.3 | 112. | .313E-02 | .232E+03 | .109E+03 | 3.26 | |
| 5 | 6.35 | 35.5 | 124. | .346E-02 | .257E+03 | .121E+03 | 0.99 | |
| 6 | 7.62 | 34.8 | 129. | .363E-02 | .269E+03 | .126E+03 | 0.14 | |
| 7 | 8.89 | 34.2 | 137. | .384E-02 | .284E+03 | .134E+03 | 0.14 | |
| 8 | 10.16 | 33.5 | 148. | .414E-02 | .306E+03 | .144E+03 | 1.70 | |
| 9 | 11.43 | 33.0 | 153. | .430E-02 | .319E+03 | .150E+03 | 0.57 | |
| 10 | 12.70 | 32.5 | 164. | .459E-02 | .340E+03 | .160E+03 | 2.13 | |
| 11 | 13.97 | 32.2 | 171. | .480E-02 | .356E+03 | .167E+03 | 2.98 | |
| 12 | 15.24 | 32.0 | 172. | .483E-02 | .358E+03 | .168E+03 | 2.22 | X_{max} |
| 13 | 17.78 | 32.3 | 171. | .479E-02 | .355E+03 | .167E+03 | 3.73 | |
| 14 | 19.05 | 32.8 | 157. | .439E-02 | .325E+03 | .153E+03 | 0.14 | |
| 15 | 20.32 | 33.3 | 148. | .415E-02 | .307E+03 | .145E+03 | 0.52 | |
| 16 | 22.86 | 34.2 | 137. | .383E-02 | .284E+03 | .133E+03 | 0.18 | |
| 17 | 25.40 | 35.0 | 127. | .355E-02 | .263E+03 | .124E+03 | 0.32 | |
| 18 | 27.94 | 35.8 | 118. | .332E-02 | .246E+03 | .116E+03 | 1.03 | |
| 19 | 30.48 | 36.3 | 115. | .322E-02 | .239E+03 | .112E+03 | 0.27 | |
| 20 | 38.10 | 37.3 | 107. | .300E-02 | .223E+03 | .105E+03 | 0.35 | |
| 21 | 40.64 | 37.4 | 107. | .299E-02 | .221E+03 | .104E+03 | 0.00 | |
| 22 | 50.80 | 37.9 | 103. | .288E-02 | .214E+03 | .100E+03 | 0.04 | |
| 23 | 63.50 | 38.3 | 100. | .281E-02 | .208E+03 | .980E+02 | 0.01 | |
| 24 | 76.20 | 38.7 | 98. | .274E-02 | .203E+03 | .953E+02 | 0.03 | |
| 25 | 88.90 | 38.9 | 96. | .270E-02 | .200E+03 | .940E+02 | 0.03 | |

Table A.81: 1 in. cylinder with $S=2$ in.; $U = 29.8(m/s)$, $T = 22.8(^{\circ}C)$,
 $q = 1549(W/m^2)$, $i = 170.0(A)$

Case: 1twd-30b

Date and time of experiment: Oct.18,1992, 02:30

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 38.7 | | | | | | |
| 2 | 2.54 | 39.1 | 96. | .267E-02 | .200E+03 | .941E+02 | 8.70 | |
| 3 | 3.81 | 38.7 | 105. | .290E-02 | .217E+03 | .102E+03 | 2.90 | |
| 4 | 5.08 | 38.2 | 108. | .300E-02 | .225E+03 | .106E+03 | 3.03 | |
| 5 | 6.35 | 37.4 | 119. | .329E-02 | .246E+03 | .116E+03 | 0.76 | |
| 6 | 7.62 | 36.6 | 124. | .345E-02 | .258E+03 | .121E+03 | 0.13 | |
| 7 | 8.89 | 35.9 | 131. | .365E-02 | .273E+03 | .128E+03 | 0.38 | |
| 8 | 10.16 | 35.2 | 139. | .387E-02 | .290E+03 | .136E+03 | 0.76 | |
| 9 | 11.43 | 34.5 | 147. | .408E-02 | .305E+03 | .144E+03 | 0.76 | |
| 10 | 12.70 | 33.9 | 157. | .436E-02 | .326E+03 | .154E+03 | 2.40 | |
| 11 | 13.97 | 33.5 | 164. | .456E-02 | .341E+03 | .160E+03 | 3.28 | |
| 12 | 15.24 | 33.4 | 165. | .457E-02 | .342E+03 | .161E+03 | 2.19 | X _{max} |
| 13 | 17.78 | 33.6 | 164. | .454E-02 | .340E+03 | .160E+03 | 3.78 | |
| 14 | 19.05 | 34.2 | 150. | .416E-02 | .311E+03 | .146E+03 | 0.00 | |
| 15 | 20.32 | 34.8 | 142. | .394E-02 | .295E+03 | .139E+03 | 0.63 | |
| 16 | 22.86 | 35.8 | 132. | .367E-02 | .274E+03 | .129E+03 | 0.06 | |
| 17 | 25.40 | 36.7 | 123. | .340E-02 | .255E+03 | .120E+03 | 0.35 | |
| 18 | 27.94 | 37.6 | 115. | .319E-02 | .239E+03 | .112E+03 | 1.01 | |
| 19 | 30.48 | 38.1 | 112. | .310E-02 | .232E+03 | .109E+03 | 0.23 | |
| 20 | 38.10 | 39.3 | 104. | .288E-02 | .215E+03 | .101E+03 | 0.40 | |
| 21 | 40.64 | 39.4 | 103. | .287E-02 | .214E+03 | .101E+03 | 0.01 | |
| 22 | 50.80 | 40.0 | 100. | .277E-02 | .207E+03 | .974E+02 | 0.04 | |
| 23 | 63.50 | 40.5 | 97. | .270E-02 | .202E+03 | .949E+02 | 0.02 | |
| 24 | 76.20 | 40.8 | 96. | .265E-02 | .199E+03 | .934E+02 | 0.00 | |
| 25 | 88.90 | 41.1 | 94. | .261E-02 | .195E+03 | .919E+02 | 0.04 | |

Table A.82: 1 in. cylinder with S=2 in.; $U = 30.1(m/s)$, $T = 22.6(^{\circ}C)$, $q = 1742(W/m^2)$, $i = 180.0(A)$

Case: 1twd-27.5

Date and time of experiment: Oct.18,1992, 01:00

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.4 | | | | | | |
| 2 | 2.54 | 37.7 | 92. | .279E-02 | .191E+03 | .898E+02 | 8.78 | |
| 3 | 3.81 | 37.4 | 99. | .301E-02 | .206E+03 | .970E+02 | 3.26 | |
| 4 | 5.08 | 36.9 | 102. | .310E-02 | .212E+03 | .997E+02 | 3.97 | |
| 5 | 6.35 | 36.1 | 113. | .344E-02 | .235E+03 | .111E+03 | 0.85 | |
| 6 | 7.62 | 35.4 | 119. | .361E-02 | .247E+03 | .116E+03 | 0.28 | |
| 7 | 8.89 | 34.7 | 125. | .381E-02 | .261E+03 | .123E+03 | 0.00 | |
| 8 | 10.16 | 34.0 | 134. | .408E-02 | .279E+03 | .131E+03 | 0.99 | |
| 9 | 11.43 | 33.4 | 143. | .434E-02 | .297E+03 | .140E+03 | 1.56 | |
| 10 | 12.70 | 32.8 | 152. | .460E-02 | .315E+03 | .148E+03 | 2.55 | |
| 11 | 13.97 | 32.5 | 158. | .478E-02 | .327E+03 | .154E+03 | 2.97 | |
| 12 | 15.24 | 32.3 | 159. | .482E-02 | .330E+03 | .155E+03 | 2.27 | X_{max} |
| 13 | 17.78 | 32.5 | 158. | .480E-02 | .329E+03 | .155E+03 | 3.97 | |
| 14 | 19.05 | 33.1 | 145. | .440E-02 | .301E+03 | .142E+03 | 0.14 | |
| 15 | 20.32 | 33.6 | 137. | .415E-02 | .284E+03 | .134E+03 | 0.76 | |
| 16 | 22.86 | 34.5 | 128. | .388E-02 | .266E+03 | .125E+03 | 0.11 | |
| 17 | 25.40 | 35.4 | 118. | .359E-02 | .246E+03 | .116E+03 | 0.28 | |
| 18 | 27.94 | 36.3 | 110. | .334E-02 | .229E+03 | .108E+03 | 1.10 | |
| 19 | 30.48 | 36.8 | 107. | .325E-02 | .222E+03 | .104E+03 | 0.25 | |
| 20 | 38.10 | 38.0 | 99. | .299E-02 | .205E+03 | .963E+02 | 0.41 | |
| 21 | 40.64 | 38.2 | 98. | .297E-02 | .203E+03 | .957E+02 | 0.03 | |
| 22 | 50.80 | 38.8 | 94. | .286E-02 | .196E+03 | .921E+02 | 0.05 | |
| 23 | 63.50 | 39.2 | 92. | .278E-02 | .191E+03 | .897E+02 | 0.03 | |
| 24 | 76.20 | 39.5 | 90. | .274E-02 | .188E+03 | .882E+02 | 0.00 | |
| 25 | 88.90 | 39.8 | 89. | .270E-02 | .185E+03 | .868E+02 | 0.04 | |

Table A.S3: 1 in. cylinder with S=2 in.; $U = 27.3(m/s)$, $T = 22.3(^{\circ}C)$,
 $q = 1550(W/m^2)$, $i = 170.0(A)$

Case: 1twd-25

Date and time of experiment: Oct.18,1992, 00:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.7 | | | | | | |
| 2 | 2.54 | 37.0 | 86. | .287E-02 | .178E+03 | .839E+02 | 9.26 | |
| 3 | 3.81 | 36.7 | 93. | .311E-02 | .193E+03 | .908E+02 | 3.67 | |
| 4 | 5.08 | 36.2 | 97. | .323E-02 | .201E+03 | .943E+02 | 3.51 | |
| 5 | 6.35 | 35.4 | 107. | .357E-02 | .222E+03 | .104E+03 | 1.12 | |
| 6 | 7.62 | 34.8 | 111. | .371E-02 | .230E+03 | .108E+03 | 0.32 | |
| 7 | 8.89 | 34.1 | 118. | .394E-02 | .245E+03 | .115E+03 | 0.16 | |
| 8 | 10.16 | 33.4 | 125. | .419E-02 | .260E+03 | .122E+03 | 0.32 | |
| 9 | 11.43 | 32.8 | 135. | .452E-02 | .281E+03 | .132E+03 | 1.76 | |
| 10 | 12.70 | 32.2 | 144. | .481E-02 | .299E+03 | .141E+03 | 2.71 | |
| 11 | 13.97 | 31.9 | 150. | .502E-02 | .312E+03 | .147E+03 | 3.19 | |
| 12 | 15.24 | 31.7 | 152. | .509E-02 | .317E+03 | .149E+03 | 2.82 | X_{max} |
| 13 | 17.78 | 31.9 | 151. | .505E-02 | .314E+03 | .148E+03 | 3.99 | |
| 14 | 19.05 | 32.4 | 139. | .465E-02 | .289E+03 | .136E+03 | 0.48 | |
| 15 | 20.32 | 32.9 | 131. | .437E-02 | .272E+03 | .128E+03 | 0.69 | |
| 16 | 22.86 | 33.7 | 122. | .407E-02 | .253E+03 | .119E+03 | 0.16 | |
| 17 | 25.40 | 34.6 | 112. | .375E-02 | .233E+03 | .110E+03 | 0.36 | |
| 18 | 27.94 | 35.5 | 104. | .349E-02 | .217E+03 | .102E+03 | 1.12 | |
| 19 | 30.48 | 36.0 | 101. | .338E-02 | .210E+03 | .987E+02 | 0.26 | |
| 20 | 38.10 | 37.2 | 92. | .309E-02 | .192E+03 | .904E+02 | 0.44 | |
| 21 | 40.64 | 37.4 | 92. | .306E-02 | .190E+03 | .896E+02 | 0.06 | |
| 22 | 50.80 | 38.0 | 88. | .294E-02 | .183E+03 | .861E+02 | 0.06 | |
| 23 | 63.50 | 38.4 | 86. | .287E-02 | .178E+03 | .838E+02 | 0.03 | |
| 24 | 76.20 | 38.7 | 85. | .283E-02 | .176E+03 | .828E+02 | 0.00 | |
| 25 | 88.90 | 38.9 | 84. | .280E-02 | .174E+03 | .818E+02 | 0.03 | |

Table A.84: 1 in. cylinder with $S=2$ in.; $U = 25.0(m/s)$, $T = 22.4(^{\circ}C)$, $q = 1376(W/m^2)$, $i = 160.0(A)$

Case: 1twd-22.5

Date and time of experiment: Oct.18,1992, 01:30

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.7 | | | | | | |
| 2 | 2.54 | 38.1 | 79. | .288E-02 | .163E+03 | .769E+02 | 9.92 | |
| 3 | 3.81 | 37.9 | 86. | .314E-02 | .178E+03 | .836E+02 | 3.52 | |
| 4 | 5.08 | 37.4 | 87. | .320E-02 | .181E+03 | .852E+02 | 4.64 | |
| 5 | 6.35 | 36.7 | 97. | .356E-02 | .202E+03 | .949E+02 | 0.96 | |
| 6 | 7.62 | 36.0 | 100. | .368E-02 | .208E+03 | .980E+02 | 0.80 | |
| 7 | 8.89 | 35.2 | 107. | .392E-02 | .222E+03 | .105E+03 | 0.00 | |
| 8 | 10.16 | 34.5 | 114. | .417E-02 | .236E+03 | .111E+03 | 0.16 | |
| 9 | 11.43 | 33.8 | 123. | .451E-02 | .255E+03 | .120E+03 | 1.76 | |
| 10 | 12.70 | 33.1 | 132. | .483E-02 | .274E+03 | .129E+03 | 3.04 | |
| 11 | 13.97 | 32.7 | 138. | .505E-02 | .286E+03 | .135E+03 | 3.52 | |
| 12 | 15.24 | 32.5 | 140. | .513E-02 | .291E+03 | .137E+03 | 3.04 | X_{max} |
| 13 | 17.78 | 32.6 | 140. | .513E-02 | .290E+03 | .137E+03 | 4.43 | |
| 14 | 19.05 | 33.1 | 128. | .471E-02 | .267E+03 | .125E+03 | 0.48 | |
| 15 | 20.32 | 33.7 | 121. | .444E-02 | .252E+03 | .118E+03 | 0.64 | |
| 16 | 22.86 | 34.6 | 113. | .414E-02 | .235E+03 | .110E+03 | 0.24 | |
| 17 | 25.40 | 35.6 | 104. | .381E-02 | .216E+03 | .102E+03 | 0.24 | |
| 18 | 27.94 | 36.5 | 96. | .353E-02 | .200E+03 | .940E+02 | 1.28 | |
| 19 | 30.48 | 37.1 | 93. | .342E-02 | .194E+03 | .911E+02 | 0.26 | |
| 20 | 38.10 | 38.5 | 85. | .311E-02 | .176E+03 | .829E+02 | 0.48 | |
| 21 | 40.64 | 38.7 | 84. | .308E-02 | .175E+03 | .821E+02 | 0.07 | |
| 22 | 50.80 | 39.5 | 80. | .294E-02 | .167E+03 | .785E+02 | 0.09 | |
| 23 | 63.50 | 39.9 | 78. | .287E-02 | .163E+03 | .766E+02 | 0.04 | |
| 24 | 76.20 | 40.1 | 78. | .284E-02 | .161E+03 | .758E+02 | 0.00 | |
| 25 | 88.90 | 40.3 | 77. | .282E-02 | .160E+03 | .751E+02 | 0.03 | |

Table A.85: 1 in. cylinder with $S=2$ in.; $U = 22.6(m/s)$, $T = 22.4(^{\circ}C)$, $q = 1373(W/m^2)$, $i = 160.0(A)$

Case: ltwd-20

Date and time of experiment: Oct.18,1992, 00:15

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 36.7 | | | | | | |
| 2 | 2.54 | 37.1 | 71. | .297E-02 | .147E+03 | .692E+02 | 11.08 | |
| 3 | 3.81 | 36.9 | 77. | .324E-02 | .160E+03 | .754E+02 | 4.36 | |
| 4 | 5.08 | 36.5 | 80. | .335E-02 | .166E+03 | .779E+02 | 4.18 | |
| 5 | 6.35 | 35.8 | 88. | .369E-02 | .182E+03 | .858E+02 | 0.73 | |
| 6 | 7.62 | 35.2 | 91. | .380E-02 | .188E+03 | .885E+02 | 0.91 | |
| 7 | 8.89 | 34.5 | 96. | .401E-02 | .199E+03 | .934E+02 | 0.73 | |
| 8 | 10.16 | 33.8 | 102. | .429E-02 | .212E+03 | .998E+02 | 0.00 | |
| 9 | 11.43 | 33.1 | 111. | .467E-02 | .231E+03 | .109E+03 | 2.18 | |
| 10 | 12.70 | 32.5 | 119. | .499E-02 | .247E+03 | .116E+03 | 3.27 | |
| 11 | 13.97 | 32.1 | 124. | .522E-02 | .258E+03 | .122E+03 | 3.82 | |
| 12 | 15.24 | 31.9 | 126. | .530E-02 | .262E+03 | .123E+03 | 3.27 | X _{max} |
| 13 | 17.78 | 32.0 | 126. | .530E-02 | .262E+03 | .123E+03 | 4.36 | |
| 14 | 19.05 | 32.4 | 117. | .491E-02 | .243E+03 | .114E+03 | 0.91 | |
| 15 | 20.32 | 32.9 | 111. | .465E-02 | .230E+03 | .108E+03 | 0.24 | |
| 16 | 22.86 | 33.8 | 103. | .431E-02 | .213E+03 | .100E+03 | 0.23 | |
| 17 | 25.40 | 34.7 | 95. | .397E-02 | .197E+03 | .925E+02 | 0.23 | |
| 18 | 27.94 | 35.6 | 87. | .367E-02 | .182E+03 | .854E+02 | 1.32 | |
| 19 | 30.48 | 36.2 | 85. | .355E-02 | .176E+03 | .826E+02 | 0.32 | |
| 20 | 38.10 | 37.6 | 77. | .322E-02 | .160E+03 | .750E+02 | 0.50 | |
| 21 | 40.64 | 37.9 | 76. | .319E-02 | .158E+03 | .741E+02 | 0.11 | |
| 22 | 50.80 | 38.6 | 72. | .304E-02 | .151E+03 | .708E+02 | 0.09 | |
| 23 | 63.50 | 39.1 | 70. | .296E-02 | .146E+03 | .688E+02 | 0.06 | |
| 24 | 76.20 | 39.3 | 70. | .292E-02 | .145E+03 | .681E+02 | 0.01 | |
| 25 | 88.90 | 39.5 | 69. | .290E-02 | .144E+03 | .675E+02 | 0.03 | |

Table A.86: 1 in. cylinder with S=2 in.; $U = 19.9(m/s)$, $T = 22.0(^{\circ}C)$,
 $q = 1209(W/m^2)$, $i = 150.0(A)$

Case: 1twd-17.5

Date and time of experiment: Oct.18,1992, 01:45

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|-------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 36.4 | | | | | | |
| 2 | 2.54 | 36.8 | 64. | .303E-02 | .132E+03 | .620E+02 | 11.29 | |
| 3 | 3.81 | 37.1 | 68. | .326E-02 | .142E+03 | .668E+02 | 5.64 | |
| 4 | 5.08 | 36.2 | 72. | .344E-02 | .150E+03 | .703E+02 | 3.76 | |
| 5 | 6.35 | 35.5 | 78. | .374E-02 | .163E+03 | .765E+02 | 0.00 | |
| 6 | 7.62 | 34.9 | 81. | .388E-02 | .169E+03 | .794E+02 | 1.04 | |
| 7 | 8.89 | 34.2 | 87. | .414E-02 | .180E+03 | .848E+02 | 0.00 | |
| 8 | 10.16 | 33.5 | 91. | .435E-02 | .189E+03 | .891E+02 | 0.84 | |
| 9 | 11.43 | 32.8 | 100. | .479E-02 | .208E+03 | .981E+02 | 2.30 | |
| 10 | 12.70 | 32.2 | 107. | .512E-02 | .223E+03 | .105E+03 | 3.13 | |
| 11 | 13.97 | 31.8 | 114. | .546E-02 | .235E+03 | .112E+03 | 5.02 | |
| 12 | 15.24 | 31.5 | 116. | .554E-02 | .241E+03 | .113E+03 | 4.04 | X _{max} |
| 13 | 17.78 | 31.7 | 115. | .547E-02 | .238E+03 | .112E+03 | 4.32 | |
| 14 | 19.05 | 32.1 | 107. | .510E-02 | .222E+03 | .104E+03 | 1.04 | |
| 15 | 20.32 | 32.5 | 101. | .483E-02 | .210E+03 | .989E+02 | 0.07 | |
| 16 | 22.86 | 33.3 | 94. | .448E-02 | .195E+03 | .917E+02 | 0.26 | |
| 17 | 25.40 | 34.2 | 87. | .413E-02 | .180E+03 | .846E+02 | 0.10 | |
| 18 | 27.94 | 35.1 | 80. | .380E-02 | .166E+03 | .779E+02 | 1.41 | |
| 19 | 30.48 | 35.7 | 77. | .367E-02 | .160E+03 | .752E+02 | 0.35 | |
| 20 | 38.10 | 37.1 | 70. | .332E-02 | .144E+03 | .679E+02 | 0.51 | |
| 21 | 40.64 | 37.4 | 68. | .327E-02 | .142E+03 | .669E+02 | 0.16 | |
| 22 | 50.80 | 38.2 | 65. | .311E-02 | .135E+03 | .636E+02 | 0.12 | |
| 23 | 63.50 | 38.8 | 63. | .301E-02 | .131E+03 | .617E+02 | 0.07 | |
| 24 | 76.20 | 38.9 | 63. | .299E-02 | .130E+03 | .611E+02 | 0.02 | |
| 25 | 88.90 | 39.0 | 62. | .297E-02 | .129E+03 | .608E+02 | 0.01 | |

Table A.87: 1 in. cylinder with S=2 in.; $U = 17.5(m/s)$, $T = 22.1(^{\circ}C)$, $q = 1051(W/m^2)$, $i = 140.0(A)$

Case: 1twd-15a

Date and time of experiment: Oct.17,1992, 23:30

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.3 | | | | | | |
| 2 | 2.54 | 35.7 | 57. | .313E-02 | .118E+03 | .554E+02 | 11.74 | |
| 3 | 3.81 | 35.7 | 60. | .332E-02 | .125E+03 | .588E+02 | 6.60 | |
| 4 | 5.08 | 35.4 | 62. | .342E-02 | .129E+03 | .605E+02 | 5.87 | |
| 5 | 6.35 | 34.9 | 68. | .377E-02 | .142E+03 | .666E+02 | 0.49 | |
| 6 | 7.62 | 34.3 | 70. | .389E-02 | .146E+03 | .688E+02 | 1.71 | |
| 7 | 8.89 | 33.7 | 75. | .412E-02 | .155E+03 | .729E+02 | 0.98 | |
| 8 | 10.16 | 33.0 | 79. | .435E-02 | .163E+03 | .769E+02 | 1.47 | |
| 9 | 11.43 | 32.3 | 88. | .483E-02 | .182E+03 | .855E+02 | 2.45 | |
| 10 | 12.70 | 31.6 | 94. | .520E-02 | .196E+03 | .920E+02 | 3.67 | |
| 11 | 13.97 | 31.2 | 100. | .555E-02 | .209E+03 | .981E+02 | 5.14 | |
| 12 | 15.24 | 30.9 | 102. | .565E-02 | .213E+03 | .100E+03 | 4.08 | |
| 13 | 17.78 | 30.9 | 103. | .571E-02 | .215E+03 | .101E+03 | 4.73 | N_{max} |
| 14 | 19.05 | 31.1 | 98. | .541E-02 | .204E+03 | .958E+02 | 2.20 | |
| 15 | 20.32 | 31.5 | 93. | .512E-02 | .193E+03 | .906E+02 | 0.41 | |
| 16 | 22.86 | 32.3 | 86. | .475E-02 | .179E+03 | .840E+02 | 0.49 | |
| 17 | 25.40 | 33.1 | 79. | .437E-02 | .164E+03 | .773E+02 | 0.12 | |
| 18 | 27.94 | 33.9 | 73. | .402E-02 | .151E+03 | .711E+02 | 1.35 | |
| 19 | 30.48 | 34.5 | 70. | .386E-02 | .145E+03 | .683E+02 | 0.44 | |
| 20 | 38.10 | 35.9 | 63. | .348E-02 | .131E+03 | .615E+02 | 0.54 | |
| 21 | 40.64 | 36.2 | 62. | .342E-02 | .129E+03 | .605E+02 | 0.17 | |
| 22 | 50.80 | 37.1 | 58. | .323E-02 | .121E+03 | .571E+02 | 0.15 | |
| 23 | 63.50 | 37.6 | 57. | .312E-02 | .117E+03 | .552E+02 | 0.08 | |
| 24 | 76.20 | 37.9 | 56. | .308E-02 | .116E+03 | .545E+02 | 0.06 | |
| 25 | 88.90 | 37.8 | 56. | .308E-02 | .116E+03 | .546E+02 | 0.00 | |

Table A.88: 1 in. cylinder with S=2 in.; $U = 15.0(m/s)$, $T = 21.8(^{\circ}C)$,
 $q = 898(W/m^2)$, $i = 130.0(A)$

Case: 1twd-15b

Date and time of experiment: Oct.18,1992, 02:15

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.1 | | | | | | |
| 2 | 2.54 | 37.9 | 56. | .318E-02 | .117E+03 | .550E+02 | 13.78 | |
| 3 | 3.81 | 38.0 | 60. | .338E-02 | .125E+03 | .586E+02 | 7.72 | |
| 4 | 5.08 | 37.7 | 62. | .348E-02 | .128E+03 | .603E+02 | 6.68 | |
| 5 | 6.35 | 37.1 | 67. | .381E-02 | .140E+03 | .659E+02 | 1.88 | |
| 6 | 7.62 | 36.4 | 71. | .400E-02 | .147E+03 | .693E+02 | 1.46 | |
| 7 | 8.89 | 35.6 | 76. | .427E-02 | .157E+03 | .740E+02 | 0.21 | |
| 8 | 10.16 | 34.9 | 80. | .451E-02 | .166E+03 | .780E+02 | 0.63 | |
| 9 | 11.43 | 34.1 | 87. | .491E-02 | .181E+03 | .850E+02 | 1.67 | |
| 10 | 12.70 | 33.4 | 94. | .529E-02 | .195E+03 | .916E+02 | 3.13 | |
| 11 | 13.97 | 32.8 | 100. | .563E-02 | .207E+03 | .975E+02 | 4.38 | |
| 12 | 15.24 | 32.4 | 103. | .582E-02 | .214E+03 | .101E+03 | 4.25 | |
| 13 | 17.78 | 32.3 | 105. | .594E-02 | .219E+03 | .103E+03 | 5.36 | X_{max} |
| 14 | 19.05 | 32.6 | 99. | .557E-02 | .205E+03 | .964E+02 | 1.88 | |
| 15 | 20.32 | 33.1 | 94. | .529E-02 | .195E+03 | .916E+02 | 0.56 | |
| 16 | 22.86 | 34.0 | 87. | .489E-02 | .180E+03 | .846E+02 | 0.47 | |
| 17 | 25.40 | 35.0 | 80. | .449E-02 | .165E+03 | .778E+02 | 0.00 | |
| 18 | 27.94 | 36.0 | 73. | .411E-02 | .151E+03 | .712E+02 | 1.46 | |
| 19 | 30.48 | 36.7 | 70. | .395E-02 | .146E+03 | .685E+02 | 0.42 | |
| 20 | 38.10 | 38.4 | 63. | .355E-02 | .130E+03 | .614E+02 | 0.50 | |
| 21 | 40.64 | 38.8 | 62. | .348E-02 | .128E+03 | .602E+02 | 0.26 | |
| 22 | 50.80 | 39.9 | 58. | .328E-02 | .121E+03 | .568E+02 | 0.15 | |
| 23 | 63.50 | 40.5 | 56. | .317E-02 | .117E+03 | .548E+02 | 0.09 | |
| 24 | 76.20 | 40.8 | 55. | .313E-02 | .115E+03 | .541E+02 | 0.05 | |
| 25 | 88.90 | 40.8 | 55. | .313E-02 | .115E+03 | .541E+02 | 0.00 | |

Table A.89: 1 in. cylinder with $S=2$ in.; $U = 14.8(m/s)$, $T = 21.8(^{\circ}C)$, $q = 1052(W/m^2)$, $i = 140.0(A)$

Case: 1twd-12.5

Date and time of experiment: Oct.18,1992, 04:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.5 | | | | | | |
| 2 | 2.54 | 37.2 | 49. | .326E-02 | .102E+03 | .480E+02 | 16.12 | |
| 3 | 3.81 | 37.3 | 54. | .357E-02 | .112E+03 | .526E+02 | 7.70 | |
| 4 | 5.08 | 37.0 | 56. | .369E-02 | .116E+03 | .543E+02 | 6.25 | |
| 5 | 6.35 | 36.5 | 61. | .402E-02 | .126E+03 | .593E+02 | 1.20 | |
| 6 | 7.62 | 35.9 | 62. | .414E-02 | .130E+03 | .610E+02 | 2.16 | |
| 7 | 8.89 | 35.3 | 66. | .436E-02 | .137E+03 | .643E+02 | 1.68 | |
| 8 | 10.16 | 34.5 | 69. | .460E-02 | .144E+03 | .678E+02 | 1.92 | |
| 9 | 11.43 | 33.7 | 77. | .511E-02 | .160E+03 | .753E+02 | 2.16 | |
| 10 | 12.70 | 33.0 | 83. | .547E-02 | .171E+03 | .806E+02 | 2.89 | |
| 11 | 13.97 | 32.4 | 89. | .590E-02 | .185E+03 | .869E+02 | 5.05 | |
| 12 | 15.24 | 32.0 | 90. | .594E-02 | .186E+03 | .876E+02 | 2.00 | |
| 13 | 17.78 | 31.5 | 106. | .704E-02 | .221E+03 | .104E+03 | 14.67 | X_{max} |
| 14 | 19.05 | 32.1 | 81. | .536E-02 | .168E+03 | .789E+02 | 6.98 | |
| 15 | 20.32 | 32.5 | 85. | .563E-02 | .177E+03 | .830E+02 | 1.20 | |
| 16 | 22.86 | 33.4 | 78. | .519E-02 | .163E+03 | .765E+02 | 0.66 | |
| 17 | 25.40 | 34.3 | 72. | .476E-02 | .149E+03 | .702E+02 | 0.12 | |
| 18 | 27.94 | 35.3 | 66. | .434E-02 | .136E+03 | .640E+02 | 1.50 | |
| 19 | 30.48 | 36.1 | 63. | .416E-02 | .130E+03 | .614E+02 | 0.47 | |
| 20 | 38.10 | 37.9 | 56. | .370E-02 | .116E+03 | .546E+02 | 0.58 | |
| 21 | 40.64 | 38.3 | 55. | .362E-02 | .114E+03 | .534E+02 | 0.28 | |
| 22 | 50.80 | 39.4 | 51. | .340E-02 | .106E+03 | .501E+02 | 0.19 | |
| 23 | 63.50 | 40.1 | 49. | .327E-02 | .102E+03 | .482E+02 | 0.12 | |
| 24 | 76.20 | 40.3 | 49. | .323E-02 | .101E+03 | .476E+02 | 0.05 | |
| 25 | 88.90 | 40.4 | 49. | .323E-02 | .101E+03 | .476E+02 | 0.00 | |

Table A.90: 1 in. cylinder with $S=2$ in.; $U = 12.5(m/s)$, $T = 21.6(^{\circ}C)$,
 $q = 913(W/m^2)$, $i = 130.0(A)$

Case: ltwd-10

Date and time of experiment: Oct.18,1992, 04:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------------|
| 1 | 1.27 | 36.0 | | | | | | |
| 2 | 2.54 | 36.8 | 42. | .349E-02 | .875E+02 | .412E+02 | 17.33 | |
| 3 | 3.81 | 36.9 | 46. | .378E-02 | .948E+02 | .446E+02 | 9.66 | |
| 4 | 5.08 | 36.7 | 47. | .389E-02 | .976E+02 | .459E+02 | 8.24 | |
| 5 | 6.35 | 36.2 | 52. | .434E-02 | .109E+03 | .512E+02 | 1.14 | |
| 6 | 7.62 | 35.7 | 53. | .442E-02 | .111E+03 | .521E+02 | 3.13 | |
| 7 | 8.89 | 35.0 | 57. | .470E-02 | .118E+03 | .554E+02 | 1.70 | |
| 8 | 10.16 | 34.3 | 60. | .497E-02 | .125E+03 | .587E+02 | 1.42 | |
| 9 | 11.43 | 33.5 | 66. | .546E-02 | .137E+03 | .644E+02 | 1.70 | |
| 10 | 12.70 | 32.8 | 71. | .590E-02 | .148E+03 | .695E+02 | 3.41 | |
| 11 | 13.97 | 32.3 | 77. | .635E-02 | .159E+03 | .749E+02 | 5.68 | |
| 12 | 15.24 | 31.7 | 79. | .658E-02 | .165E+03 | .776E+02 | 5.59 | |
| 13 | 17.78 | 31.7 | 81. | .674E-02 | .169E+03 | .795E+02 | 6.34 | λ_{max} |
| 14 | 19.05 | 32.0 | 77. | .635E-02 | .159E+03 | .748E+02 | 2.56 | |
| 15 | 20.32 | 32.3 | 73. | .606E-02 | .152E+03 | .715E+02 | 1.14 | |
| 16 | 22.86 | 33.1 | 68. | .563E-02 | .141E+03 | .664E+02 | 0.99 | |
| 17 | 25.40 | 34.0 | 62. | .516E-02 | .129E+03 | .609E+02 | 0.21 | |
| 18 | 27.94 | 35.0 | 57. | .470E-02 | .118E+03 | .554E+02 | 1.63 | |
| 19 | 30.48 | 35.8 | 54. | .451E-02 | .113E+03 | .532E+02 | 0.43 | |
| 20 | 38.10 | 37.6 | 48. | .398E-02 | .997E+02 | .469E+02 | 0.67 | |
| 21 | 40.64 | 38.0 | 47. | .388E-02 | .974E+02 | .458E+02 | 0.36 | |
| 22 | 50.80 | 39.3 | 44. | .362E-02 | .908E+02 | .427E+02 | 0.23 | |
| 23 | 63.50 | 40.0 | 42. | .347E-02 | .870E+02 | .409E+02 | 0.15 | |
| 24 | 76.20 | 40.3 | 41. | .342E-02 | .858E+02 | .404E+02 | 0.10 | |
| 25 | 88.90 | 40.2 | 42. | .344E-02 | .863E+02 | .406E+02 | 0.02 | |

Table A.91: 1 in. cylinder with S=2 in.; $U = 10.0(m/s)$, $T = 21.6(^{\circ}C)$, $q = 773(W/m^2)$, $i = 120.0(A)$

Case: 1twd-8.7

Date and time of experiment: Oct.18,1992, 03:30

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 34.9 | | | | | | |
| 2 | 2.54 | 35.6 | 38. | .357E-02 | .779E+02 | .366E+02 | 19.13 | |
| 3 | 3.81 | 35.8 | 41. | .388E-02 | .845E+02 | .398E+02 | 11.07 | |
| 4 | 5.08 | 35.7 | 42. | .399E-02 | .870E+02 | .409E+02 | 9.40 | |
| 5 | 6.35 | 35.2 | 46. | .440E-02 | .959E+02 | .451E+02 | 3.02 | |
| 6 | 7.62 | 34.7 | 48. | .458E-02 | .100E+03 | .470E+02 | 2.68 | |
| 7 | 8.89 | 34.1 | 51. | .485E-02 | .106E+03 | .497E+02 | 1.68 | |
| 8 | 10.16 | 33.5 | 53. | .507E-02 | .111E+03 | .520E+02 | 2.35 | |
| 9 | 11.43 | 32.8 | 59. | .558E-02 | .122E+03 | .572E+02 | 1.01 | |
| 10 | 12.70 | 32.1 | 64. | .613E-02 | .134E+03 | .629E+02 | 4.36 | |
| 11 | 13.97 | 31.6 | 69. | .659E-02 | .144E+03 | .676E+02 | 6.38 | |
| 12 | 15.24 | 31.2 | 72. | .684E-02 | .149E+03 | .702E+02 | 6.49 | |
| 13 | 17.78 | 31.1 | 72. | .688E-02 | .150E+03 | .706E+02 | 5.59 | X_{max} |
| 14 | 19.05 | 31.2 | 69. | .661E-02 | .144E+03 | .678E+02 | 3.36 | |
| 15 | 20.32 | 31.5 | 67. | .635E-02 | .139E+03 | .652E+02 | 2.13 | |
| 16 | 22.86 | 32.3 | 61. | .583E-02 | .127E+03 | .599E+02 | 0.84 | |
| 17 | 25.40 | 33.1 | 57. | .539E-02 | .117E+03 | .553E+02 | 0.42 | |
| 18 | 27.94 | 34.0 | 51. | .489E-02 | .107E+03 | .502E+02 | 1.76 | |
| 19 | 30.48 | 34.7 | 49. | .470E-02 | .102E+03 | .482E+02 | 0.42 | |
| 20 | 38.10 | 36.5 | 43. | .414E-02 | .902E+02 | .424E+02 | 0.59 | |
| 21 | 40.64 | 36.9 | 42. | .402E-02 | .877E+02 | .412E+02 | 0.49 | |
| 22 | 50.80 | 38.1 | 39. | .374E-02 | .815E+02 | .383E+02 | 0.26 | |
| 23 | 63.50 | 38.9 | 37. | .356E-02 | .778E+02 | .366E+02 | 0.18 | |
| 24 | 76.20 | 39.2 | 37. | .351E-02 | .766E+02 | .360E+02 | 0.14 | |
| 25 | 88.90 | 39.1 | 37. | .354E-02 | .773E+02 | .363E+02 | 0.04 | |

Table A.92: 1 in. cylinder with $S=2$ in.; $U = 8.7(m/s)$, $T = 21.5(^{\circ}C)$,
 $q = 654(W/m^2)$, $i = 110.0(A)$

Case: 1twd-7.5a

Date and time of experiment: Oct.18,1992, 03:00

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 34.7 | | | | | | |
| 2 | 2.54 | 35.1 | 33. | .372E-02 | .694E+02 | .326E+02 | 15.95 | |
| 3 | 3.81 | 35.2 | 36. | .403E-02 | .752E+02 | .354E+02 | 8.59 | |
| 4 | 5.08 | 35.0 | 36. | .403E-02 | .751E+02 | .353E+02 | 9.81 | |
| 5 | 6.35 | 34.6 | 40. | .444E-02 | .828E+02 | .389E+02 | 3.68 | |
| 6 | 7.62 | 34.1 | 42. | .466E-02 | .868E+02 | .408E+02 | 2.86 | |
| 7 | 8.89 | 33.5 | 44. | .492E-02 | .918E+02 | .432E+02 | 2.05 | |
| 8 | 10.16 | 32.9 | 47. | .519E-02 | .968E+02 | .455E+02 | 2.04 | |
| 9 | 11.43 | 32.2 | 51. | .568E-02 | .106E+03 | .498E+02 | 0.82 | |
| 10 | 12.70 | 31.6 | 57. | .632E-02 | .118E+03 | .554E+02 | 5.31 | |
| 11 | 13.97 | 31.1 | 61. | .685E-02 | .128E+03 | .601E+02 | 8.18 | |
| 12 | 15.24 | 30.7 | 62. | .695E-02 | .130E+03 | .609E+02 | 6.00 | |
| 13 | 17.78 | 30.5 | 64. | .716E-02 | .133E+03 | .628E+02 | 6.81 | X_{max} |
| 14 | 19.05 | 30.7 | 62. | .689E-02 | .128E+03 | .604E+02 | 4.50 | |
| 15 | 20.32 | 30.9 | 58. | .650E-02 | .121E+03 | .570E+02 | 1.50 | |
| 16 | 22.86 | 31.6 | 55. | .608E-02 | .113E+03 | .533E+02 | 1.33 | |
| 17 | 25.40 | 32.3 | 50. | .561E-02 | .105E+03 | .492E+02 | 0.61 | |
| 18 | 27.94 | 33.2 | 46. | .510E-02 | .951E+02 | .447E+02 | 1.53 | |
| 19 | 30.48 | 33.8 | 44. | .487E-02 | .908E+02 | .427E+02 | 0.56 | |
| 20 | 38.10 | 35.5 | 38. | .427E-02 | .797E+02 | .375E+02 | 0.72 | |
| 21 | 40.64 | 35.9 | 37. | .416E-02 | .775E+02 | .365E+02 | 0.48 | |
| 22 | 50.80 | 37.1 | 34. | .384E-02 | .716E+02 | .337E+02 | 0.32 | |
| 23 | 63.50 | 37.9 | 33. | .366E-02 | .682E+02 | .321E+02 | 0.20 | |
| 24 | 76.20 | 38.3 | 32. | .359E-02 | .669E+02 | .315E+02 | 0.22 | |
| 25 | 88.90 | 38.0 | 33. | .365E-02 | .680E+02 | .320E+02 | 0.09 | |

Table A.93: 1 in. cylinder with $S=2$ in.; $U = 7.5(m/s)$, $T = 21.6(^{\circ}C)$, $q = 537(W/m^2)$, $i = 100.0(A)$

Case: 1twd-7.5b

Date and time of experiment: Oct.18,1992, 05:00

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.0 | | | | | | |
| 2 | 2.54 | 36.8 | 34. | .384E-02 | .713E+02 | .335E+02 | 18.73 | |
| 3 | 3.81 | 36.9 | 37. | .412E-02 | .765E+02 | .360E+02 | 11.58 | |
| 4 | 5.08 | 36.8 | 38. | .423E-02 | .784E+02 | .369E+02 | 10.21 | |
| 5 | 6.35 | 36.4 | 42. | .470E-02 | .872E+02 | .410E+02 | 3.06 | |
| 6 | 7.62 | 35.8 | 43. | .485E-02 | .901E+02 | .424E+02 | 3.40 | |
| 7 | 8.89 | 35.2 | 46. | .513E-02 | .952E+02 | .448E+02 | 2.38 | |
| 8 | 10.16 | 34.5 | 48. | .537E-02 | .996E+02 | .468E+02 | 3.06 | |
| 9 | 11.43 | 33.7 | 54. | .601E-02 | .112E+03 | .525E+02 | 2.04 | |
| 10 | 12.70 | 33.0 | 59. | .657E-02 | .122E+03 | .573E+02 | 4.77 | |
| 11 | 13.97 | 32.4 | 63. | .701E-02 | .130E+03 | .612E+02 | 6.13 | |
| 12 | 15.24 | 32.0 | 65. | .729E-02 | .135E+03 | .636E+02 | 6.24 | |
| 13 | 17.78 | 31.7 | 68. | .758E-02 | .141E+03 | .662E+02 | 7.60 | X_{max} |
| 14 | 19.05 | 31.9 | 64. | .714E-02 | .133E+03 | .624E+02 | 3.41 | |
| 15 | 20.32 | 32.2 | 61. | .682E-02 | .126E+03 | .595E+02 | 1.48 | |
| 16 | 22.86 | 32.9 | 57. | .639E-02 | .118E+03 | .557E+02 | 1.53 | |
| 17 | 25.40 | 33.9 | 52. | .586E-02 | .109E+03 | .511E+02 | 0.51 | |
| 18 | 27.94 | 34.8 | 47. | .531E-02 | .986E+02 | .464E+02 | 1.70 | |
| 19 | 30.48 | 35.6 | 45. | .508E-02 | .943E+02 | .444E+02 | 0.50 | |
| 20 | 38.10 | 37.6 | 40. | .446E-02 | .827E+02 | .389E+02 | 0.70 | |
| 21 | 40.64 | 38.1 | 39. | .434E-02 | .804E+02 | .378E+02 | 0.45 | |
| 22 | 50.80 | 39.5 | 36. | .400E-02 | .742E+02 | .349E+02 | 0.31 | |
| 23 | 63.50 | 40.4 | 34. | .380E-02 | .705E+02 | .332E+02 | 0.20 | |
| 24 | 76.20 | 40.8 | 33. | .373E-02 | .692E+02 | .325E+02 | 0.19 | |
| 25 | 88.90 | 40.6 | 34. | .378E-02 | .701E+02 | .330E+02 | 0.07 | |

Table A.94: 1 in. cylinder with S=2 in.; $U = 7.4(m/s)$, $T = 21.5(^{\circ}C)$,
 $q = 645(W/m^2)$, $i = 110.0(A)$

Case: 1twd-06

Date and time of experiment: Oct.18,1992, 04:30

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 35.5 | | | | | | |
| 2 | 2.54 | 36.2 | 29. | .407E-02 | .612E+02 | .288E+02 | 18.48 | |
| 3 | 3.81 | 36.4 | 31. | .430E-02 | .646E+02 | .304E+02 | 12.73 | |
| 4 | 5.08 | 36.3 | 32. | .437E-02 | .658E+02 | .309E+02 | 11.91 | |
| 5 | 6.35 | 35.8 | 36. | .494E-02 | .743E+02 | .349E+02 | 3.28 | |
| 6 | 7.62 | 35.4 | 36. | .502E-02 | .756E+02 | .355E+02 | 4.93 | |
| 7 | 8.89 | 34.7 | 39. | .536E-02 | .807E+02 | .380E+02 | 2.87 | |
| 8 | 10.16 | 34.1 | 41. | .565E-02 | .850E+02 | .400E+02 | 2.87 | |
| 9 | 11.43 | 33.3 | 46. | .629E-02 | .946E+02 | .445E+02 | 1.64 | |
| 10 | 12.70 | 32.6 | 50. | .693E-02 | .104E+03 | .490E+02 | 5.34 | |
| 11 | 13.97 | 32.0 | 54. | .750E-02 | .113E+03 | .531E+02 | 8.21 | |
| 12 | 15.24 | 31.6 | 56. | .772E-02 | .116E+03 | .546E+02 | 7.39 | |
| 13 | 17.78 | 31.4 | 57. | .791E-02 | .119E+03 | .560E+02 | 7.66 | X_{max} |
| 14 | 19.05 | 31.6 | 54. | .746E-02 | .112E+03 | .528E+02 | 3.28 | |
| 15 | 20.32 | 31.8 | 52. | .723E-02 | .109E+03 | .511E+02 | 2.46 | |
| 16 | 22.86 | 32.5 | 49. | .673E-02 | .101E+03 | .476E+02 | 1.64 | |
| 17 | 25.40 | 33.4 | 45. | .622E-02 | .935E+02 | .440E+02 | 0.92 | |
| 18 | 27.94 | 34.3 | 41. | .560E-02 | .843E+02 | .397E+02 | 1.95 | |
| 19 | 30.48 | 35.0 | 39. | .538E-02 | .809E+02 | .381E+02 | 0.51 | |
| 20 | 38.10 | 36.9 | 34. | .471E-02 | .708E+02 | .333E+02 | 0.67 | |
| 21 | 40.64 | 37.5 | 33. | .456E-02 | .686E+02 | .323E+02 | 0.60 | |
| 22 | 50.80 | 38.9 | 30. | .419E-02 | .631E+02 | .297E+02 | 0.37 | |
| 23 | 63.50 | 39.9 | 29. | .397E-02 | .597E+02 | .281E+02 | 0.26 | |
| 24 | 76.20 | 40.3 | 28. | .389E-02 | .584E+02 | .275E+02 | 0.30 | |
| 25 | 88.90 | 40.0 | 29. | .398E-02 | .598E+02 | .282E+02 | 0.15 | |

Table A.95: 1 in. cylinder with $S=2$ in.; $U = 6.0(m/s)$, $T = 21.4(^{\circ}C)$, $q = 535(W/m^2)$, $i = 100.0(A)$

Case: 1twd-05

Date and time of experiment: Oct.18,1992, 03:15

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|-------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 34.1 | | | | | | |
| 2 | 2.54 | 34.6 | 26. | .439E-02 | .550E+02 | .259E+02 | 19.66 | |
| 3 | 3.81 | 34.8 | 28. | .471E-02 | .591E+02 | .278E+02 | 12.61 | |
| 4 | 5.08 | 34.7 | 27. | .452E-02 | .567E+02 | .267E+02 | 16.64 | |
| 5 | 6.35 | 34.3 | 33. | .554E-02 | .695E+02 | .327E+02 | 1.01 | |
| 6 | 7.62 | 33.9 | 33. | .553E-02 | .693E+02 | .326E+02 | 4.54 | |
| 7 | 8.89 | 33.4 | 36. | .592E-02 | .742E+02 | .349E+02 | 2.02 | |
| 8 | 10.16 | 32.8 | 37. | .612E-02 | .767E+02 | .361E+02 | 3.53 | |
| 9 | 11.43 | 32.2 | 41. | .675E-02 | .846E+02 | .398E+02 | 0.50 | |
| 10 | 12.70 | 31.6 | 46. | .755E-02 | .947E+02 | .445E+02 | 6.05 | |
| 11 | 13.97 | 31.1 | 50. | .836E-02 | .105E+03 | .493E+02 | 11.60 | |
| 12 | 15.24 | 30.8 | 49. | .815E-02 | .102E+03 | .481E+02 | 5.71 | |
| 13 | 17.78 | 30.6 | 51. | .851E-02 | .107E+03 | .502E+02 | 8.07 | X_{max} |
| 14 | 19.05 | 30.7 | 49. | .811E-02 | .102E+03 | .478E+02 | 4.54 | |
| 15 | 20.32 | 31.0 | 47. | .779E-02 | .976E+02 | .459E+02 | 2.86 | |
| 16 | 22.86 | 31.6 | 43. | .718E-02 | .900E+02 | .424E+02 | 1.13 | |
| 17 | 25.40 | 32.3 | 40. | .668E-02 | .838E+02 | .394E+02 | 0.76 | |
| 18 | 27.94 | 33.1 | 37. | .608E-02 | .762E+02 | .358E+02 | 1.76 | |
| 19 | 30.48 | 33.7 | 35. | .585E-02 | .733E+02 | .345E+02 | 0.27 | |
| 20 | 38.10 | 35.5 | 31. | .507E-02 | .636E+02 | .299E+02 | 0.92 | |
| 21 | 40.64 | 36.0 | 30. | .493E-02 | .619E+02 | .291E+02 | 0.57 | |
| 22 | 50.80 | 37.3 | 27. | .452E-02 | .567E+02 | .267E+02 | 0.42 | |
| 23 | 63.50 | 38.3 | 26. | .428E-02 | .536E+02 | .252E+02 | 0.28 | |
| 24 | 76.20 | 38.7 | 25. | .417E-02 | .523E+02 | .246E+02 | 0.41 | |
| 25 | 88.90 | 38.2 | 26. | .430E-02 | .540E+02 | .254E+02 | 0.21 | |

Table A.96: 1 in. cylinder with $S=2$ in.; $U = 5.0(m/s)$, $T = 21.4(^{\circ}C)$, $q = 436(W/m^2)$, $i = 90.0(A)$

A.a-vii Data and Results for 2" cylinder in Different Velocities; $S = 1''$, $D = 4''$

Case: 2twa-30a

Date and time of experiment: Aug.22,1992, 15:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|--------|-------|------|----------|----------|----------|-------|--------------|
| 1 | 1.27 | 36.9 | | | | | | |
| 2 | 2.54 | 34.7 | 104. | .290E-02 | .102E+03 | .203E+03 | 13.46 | |
| 3 | 5.08 | 31.8 | 134. | .373E-02 | .131E+03 | .261E+03 | 10.63 | |
| 4 | 6.35 | 31.0 | 141. | .392E-02 | .137E+03 | .275E+03 | 5.58 | |
| 5 | 7.62 | 30.4 | 154. | .429E-02 | .150E+03 | .301E+03 | 6.82 | |
| 6 | 10.16 | 29.9 | 166. | .463E-02 | .162E+03 | .324E+03 | 8.06 | χ_{max} |
| 7 | 11.43 | 30.1 | 150. | .418E-02 | .146E+03 | .293E+03 | 0.53 | |
| 8 | 12.70 | 30.4 | 160. | .445E-02 | .156E+03 | .312E+03 | 10.63 | |
| 9 | 13.97 | 31.0 | 124. | .346E-02 | .121E+03 | .243E+03 | 6.64 | |
| 10 | 15.24 | 31.4 | 128. | .357E-02 | .125E+03 | .250E+03 | 0.80 | |
| 11 | 16.51 | 31.8 | 114. | .319E-02 | .112E+03 | .223E+03 | 5.58 | |
| 12 | 17.78 | 32.0 | 121. | .337E-02 | .118E+03 | .236E+03 | 2.04 | |
| 13 | 20.32 | 32.7 | 109. | .305E-02 | .107E+03 | .213E+03 | 1.17 | |
| 14 | 25.40 | 33.5 | 102. | .285E-02 | .998E+02 | .200E+03 | 0.35 | |
| 15 | 30.48 | 34.0 | 97. | .271E-02 | .948E+02 | .190E+03 | 0.32 | |
| 16 | 40.64 | 34.6 | 93. | .259E-02 | .906E+02 | .181E+03 | 0.04 | |
| 17 | 50.80 | 35.0 | 89. | .249E-02 | .873E+02 | .175E+03 | 0.01 | |
| 18 | 63.50 | 35.6 | 86. | .239E-02 | .836E+02 | .167E+03 | 0.09 | |
| 19 | 76.20 | 35.7 | 84. | .235E-02 | .825E+02 | .165E+03 | 0.06 | |
| 20 | 88.90 | 35.7 | 85. | .237E-02 | .829E+02 | .166E+03 | 0.00 | |
| 21 | 101.60 | 35.6 | 85. | .238E-02 | .832E+02 | .166E+03 | 0.01 | |

Table A.97: 2 in. cylinder with $S=1$ in.; $U = 29.7(m/s)$, $T = 22.8(^{\circ}C)$,
 $q = 1090(W/m^2)$, $i = 333.3(A)$

Case: 2twa-30b

Date and time of experiment: Sep.7,1992, 10:30

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|--------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.1 | | | | | | |
| 2 | 2.54 | 34.0 | 109. | .304E-02 | .107E+03 | .213E+03 | 13.48 | |
| 3 | 5.08 | 31.3 | 141. | .392E-02 | .137E+03 | .275E+03 | 10.80 | |
| 4 | 6.35 | 30.5 | 141. | .393E-02 | .138E+03 | .276E+03 | 1.34 | |
| 5 | 7.62 | 29.8 | 167. | .466E-02 | .164E+03 | .327E+03 | 9.11 | |
| 6 | 10.16 | 29.4 | 175. | .487E-02 | .171E+03 | .342E+03 | 7.50 | X_{max} |
| 7 | 11.45 | 29.6 | 159. | .443E-02 | .155E+03 | .311E+03 | 1.07 | |
| 8 | 12.70 | 29.9 | 166. | .461E-02 | .162E+03 | .323E+03 | 9.11 | |
| 9 | 13.97 | 30.5 | 133. | .370E-02 | .130E+03 | .260E+03 | 5.09 | |
| 10 | 15.24 | 30.9 | 133. | .370E-02 | .130E+03 | .260E+03 | 0.00 | |
| 11 | 16.51 | 31.3 | 123. | .344E-02 | .121E+03 | .241E+03 | 2.41 | |
| 12 | 17.78 | 31.6 | 122. | .339E-02 | .119E+03 | .238E+03 | 0.09 | |
| 13 | 20.32 | 32.3 | 113. | .313E-02 | .110E+03 | .220E+03 | 1.16 | |
| 14 | 25.40 | 33.0 | 105. | .293E-02 | .103E+03 | .206E+03 | 0.37 | |
| 15 | 30.48 | 33.5 | 100. | .279E-02 | .979E+02 | .196E+03 | 0.30 | |
| 16 | 40.64 | 34.0 | 96. | .267E-02 | .938E+02 | .188E+03 | 0.03 | |
| 17 | 50.80 | 34.5 | 92. | .257E-02 | .902E+02 | .180E+03 | 0.01 | |
| 18 | 63.50 | 35.0 | 88. | .246E-02 | .862E+02 | .172E+03 | 0.09 | |
| 19 | 76.20 | 35.2 | 87. | .242E-02 | .849E+02 | .170E+03 | 0.04 | |
| 20 | 88.90 | 35.3 | 87. | .241E-02 | .845E+02 | .169E+03 | 0.02 | |
| 21 | 101.60 | 35.2 | 87. | .242E-02 | .848E+02 | .170E+03 | 0.01 | |

Table A.98: 2 in. cylinder with $S=1$ in.; $U = 30.0(m/s)$, $T = 22.8(^{\circ}C)$, $q = 1082(W/m^2)$, $i = 333.3(A)$

Case: 2twa-27.5

Date and time of experiment: Sep.7,1992, 11:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|--------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 36.7 | | | | | | |
| 2 | 2.54 | 34.6 | 102. | .311E-02 | .100E+03 | .200E+03 | 12.11 | |
| 3 | 5.08 | 31.8 | 133. | .404E-02 | .130E+03 | .260E+03 | 10.50 | |
| 4 | 6.35 | 30.9 | 134. | .408E-02 | .131E+03 | .263E+03 | 1.34 | |
| 5 | 7.62 | 30.1 | 161. | .490E-02 | .158E+03 | .315E+03 | 9.97 | |
| 6 | 10.16 | 29.7 | 169. | .513E-02 | .165E+03 | .330E+03 | 7.83 | X_{max} |
| 7 | 11.43 | 29.9 | 154. | .469E-02 | .151E+03 | .302E+03 | 1.60 | |
| 8 | 12.70 | 30.2 | 160. | .486E-02 | .156E+03 | .313E+03 | 9.35 | |
| 9 | 13.97 | 30.8 | 129. | .392E-02 | .126E+03 | .252E+03 | 4.54 | |
| 10 | 15.24 | 31.2 | 128. | .388E-02 | .125E+03 | .249E+03 | 0.27 | |
| 11 | 16.51 | 31.7 | 119. | .363E-02 | .117E+03 | .233E+03 | 1.87 | |
| 12 | 17.78 | 32.0 | 116. | .353E-02 | .114E+03 | .227E+03 | 0.44 | |
| 13 | 20.32 | 32.7 | 107. | .326E-02 | .105E+03 | .210E+03 | 1.25 | |
| 14 | 25.40 | 33.6 | 100. | .304E-02 | .977E+02 | .195E+03 | 0.40 | |
| 15 | 30.48 | 34.1 | 95. | .289E-02 | .928E+02 | .186E+03 | 0.33 | |
| 16 | 40.64 | 34.7 | 91. | .276E-02 | .887E+02 | .177E+03 | 0.03 | |
| 17 | 50.80 | 35.2 | 87. | .265E-02 | .852E+02 | .170E+03 | 0.02 | |
| 18 | 63.50 | 35.8 | 83. | .253E-02 | .814E+02 | .163E+03 | 0.09 | |
| 19 | 76.20 | 36.0 | 82. | .249E-02 | .801E+02 | .160E+03 | 0.04 | |
| 20 | 88.90 | 36.0 | 82. | .248E-02 | .797E+02 | .159E+03 | 0.02 | |
| 21 | 101.60 | 36.0 | 82. | .248E-02 | .798E+02 | .160E+03 | 0.00 | |

Table A.99: 2 in. cylinder with $S=1$ in.; $U = 27.5(m/s)$, $T = 22.8(^{\circ}C)$, $\dot{q} = 1085(W/m^2)$, $i = 333.3(A)$

Case: 2twa-25

Date and time of experiment: Aug.22,1992, 15:00

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|--------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 37.6 | | | | | | |
| 2 | 2.54 | 35.5 | 95. | .315E-02 | .929E+02 | .186E+03 | 10.88 | |
| 3 | 5.08 | 32.5 | 124. | .409E-02 | .121E+03 | .241E+03 | 9.82 | |
| 4 | 6.35 | 31.5 | 133. | .440E-02 | .130E+03 | .259E+03 | 6.37 | |
| 5 | 7.62 | 30.8 | 146. | .483E-02 | .142E+03 | .285E+03 | 7.07 | |
| 6 | 10.16 | 30.2 | 161. | .534E-02 | .157E+03 | .315E+03 | 9.02 | X_{max} |
| 7 | 11.43 | 30.4 | 146. | .482E-02 | .142E+03 | .285E+03 | 1.06 | |
| 8 | 12.70 | 30.6 | 156. | .517E-02 | .153E+03 | .305E+03 | 11.67 | |
| 9 | 13.97 | 31.3 | 122. | .403E-02 | .119E+03 | .238E+03 | 5.57 | |
| 10 | 15.24 | 31.7 | 123. | .407E-02 | .120E+03 | .240E+03 | 0.53 | |
| 11 | 16.51 | 32.2 | 110. | .364E-02 | .107E+03 | .215E+03 | 5.31 | |
| 12 | 17.78 | 32.5 | 115. | .380E-02 | .112E+03 | .224E+03 | 1.95 | |
| 13 | 20.32 | 33.3 | 103. | .341E-02 | .100E+03 | .201E+03 | 1.37 | |
| 14 | 25.40 | 34.2 | 95. | .316E-02 | .930E+02 | .186E+03 | 0.43 | |
| 15 | 30.48 | 34.9 | 90. | .298E-02 | .879E+02 | .176E+03 | 0.36 | |
| 16 | 40.64 | 35.6 | 85. | .283E-02 | .833E+02 | .167E+03 | 0.07 | |
| 17 | 50.80 | 36.1 | 82. | .271E-02 | .800E+02 | .160E+03 | 0.01 | |
| 18 | 63.50 | 36.7 | 78. | .259E-02 | .764E+02 | .153E+03 | 0.10 | |
| 19 | 76.20 | 37.0 | 77. | .255E-02 | .752E+02 | .150E+03 | 0.05 | |
| 20 | 88.90 | 37.0 | 77. | .255E-02 | .751E+02 | .150E+03 | 0.01 | |
| 21 | 101.60 | 37.0 | 77. | .255E-02 | .751E+02 | .150E+03 | 0.00 | |

Table A.100: 2 in. cylinder with $S=1$ in.; $U = 25.0(m/s)$, $T = 22.8(^{\circ}C)$,
 $q = 1092(W/m^2)$, $i = 333.3(A)$

Case: 2twa-22.5

Date and time of experiment: Sep.7,1992, 11:45

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|--------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 38.8 | | | | | | |
| 2 | 2.54 | 36.7 | 84. | .313E-02 | .819E+02 | .164E+03 | 10.02 | |
| 3 | 5.08 | 33.6 | 107. | .398E-02 | .104E+03 | .208E+03 | 9.49 | |
| 4 | 6.35 | 32.6 | 110. | .409E-02 | .107E+03 | .214E+03 | 2.39 | |
| 5 | 7.62 | 31.6 | 130. | .486E-02 | .127E+03 | .255E+03 | 10.55 | |
| 6 | 10.16 | 30.9 | 139. | .517E-02 | .135E+03 | .271E+03 | 8.96 | X_{max} |
| 7 | 11.43 | 31.1 | 128. | .477E-02 | .125E+03 | .250E+03 | 2.66 | |
| 8 | 12.70 | 31.4 | 135. | .502E-02 | .131E+03 | .263E+03 | 11.18 | |
| 9 | 13.97 | 32.1 | 107. | .400E-02 | .105E+03 | .210E+03 | 4.52 | |
| 10 | 15.24 | 32.6 | 107. | .398E-02 | .104E+03 | .208E+03 | 0.00 | |
| 11 | 16.51 | 33.1 | 100. | .373E-02 | .978E+02 | .196E+03 | 1.33 | |
| 12 | 17.78 | 33.6 | 96. | .360E-02 | .942E+02 | .188E+03 | 0.80 | |
| 13 | 20.32 | 34.4 | 89. | .332E-02 | .870E+02 | .174E+03 | 1.42 | |
| 14 | 25.40 | 35.5 | 83. | .308E-02 | .807E+02 | .161E+03 | 0.53 | |
| 15 | 30.48 | 36.2 | 78. | .292E-02 | .765E+02 | .153E+03 | 0.42 | |
| 16 | 40.64 | 37.0 | 75. | .279E-02 | .730E+02 | .146E+03 | 0.06 | |
| 17 | 50.80 | 37.5 | 72. | .268E-02 | .702E+02 | .140E+03 | 0.01 | |
| 18 | 63.50 | 38.2 | 69. | .256E-02 | .670E+02 | .134E+03 | 0.11 | |
| 19 | 76.20 | 38.5 | 67. | .251E-02 | .659E+02 | .132E+03 | 0.04 | |
| 20 | 88.90 | 38.7 | 67. | .249E-02 | .653E+02 | .131E+03 | 0.03 | |
| 21 | 101.60 | 38.7 | 67. | .249E-02 | .653E+02 | .131E+03 | 0.01 | |

Table A.101: 2 in. cylinder with $S=1$ in.; $U = 22.4(m/s)$, $T = 22.4(^{\circ}C)$, $q = 1089(W/m^2)$, $i = 333.3(A)$

Case: 2twa-20

Date and time of experiment: Aug.22,1992, 14:00

| No. | X(cm) | T(°C) | h | St | Nu _s | Nu _d | cond% | |
|-----|--------|-------|------|----------|-----------------|-----------------|-------|------------------------|
| 1 | 1.27 | 39.0 | | | | | | |
| 2 | 2.54 | 37.1 | 79. | .323E-02 | .770E+02 | .154E+03 | 5.74 | |
| 3 | 5.08 | 34.1 | 101. | .415E-02 | .988E+02 | .198E+03 | 7.50 | |
| 4 | 6.35 | 33.0 | 110. | .450E-02 | .107E+03 | .214E+03 | 5.56 | |
| 5 | 7.62 | 32.1 | 122. | .502E-02 | .120E+03 | .239E+03 | 7.85 | |
| 6 | 10.16 | 31.2 | 138. | .566E-02 | .135E+03 | .270E+03 | 10.33 | <i>X_{max}</i> |
| 7 | 11.43 | 31.3 | 126. | .517E-02 | .123E+03 | .246E+03 | 2.38 | |
| 8 | 12.70 | 31.6 | 136. | .557E-02 | .133E+03 | .265E+03 | 13.24 | |
| 9 | 13.97 | 32.3 | 106. | .434E-02 | .103E+03 | .207E+03 | 4.77 | |
| 10 | 15.24 | 32.8 | 105. | .433E-02 | .103E+03 | .206E+03 | 0.26 | |
| 11 | 16.51 | 33.4 | 96. | .394E-02 | .939E+02 | .188E+03 | 3.71 | |
| 12 | 17.78 | 33.8 | 97. | .398E-02 | .949E+02 | .190E+03 | 1.06 | |
| 13 | 20.32 | 34.8 | 87. | .358E-02 | .853E+02 | .171E+03 | 1.54 | |
| 14 | 25.40 | 36.0 | 80. | .329E-02 | .784E+02 | .157E+03 | 0.56 | |
| 15 | 30.48 | 36.9 | 75. | .309E-02 | .737E+02 | .147E+03 | 0.47 | |
| 16 | 40.64 | 37.8 | 71. | .292E-02 | .696E+02 | .139E+03 | 0.12 | |
| 17 | 50.80 | 38.4 | 69. | .281E-02 | .670E+02 | .134E+03 | 0.00 | |
| 18 | 63.50 | 39.2 | 65. | .268E-02 | .638E+02 | .128E+03 | 0.12 | |
| 19 | 76.20 | 39.5 | 64. | .263E-02 | .627E+02 | .125E+03 | 0.04 | |
| 20 | 88.90 | 39.6 | 64. | .261E-02 | .622E+02 | .124E+03 | 0.03 | |
| 21 | 101.60 | 39.7 | 64. | .261E-02 | .621E+02 | .124E+03 | 0.01 | |

Table A.102: 2 in. cylinder with S=1 in.; $U = 20.2(m/s)$, $T = 22.4(^{\circ}C)$, $q = 1094(W/m^2)$, $i = 333.3(A)$

Case: 2twa-17.5

Date and time of experiment: Sep.7,1992, 12:10

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|--------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 40.2 | | | | | | |
| 2 | 2.54 | 38.2 | 70. | .337E-02 | .687E+02 | .137E+03 | 6.84 | |
| 3 | 5.08 | 34.8 | 89. | .429E-02 | .872E+02 | .174E+03 | 8.10 | |
| 4 | 6.35 | 33.6 | 94. | .450E-02 | .916E+02 | .183E+03 | 2.97 | |
| 5 | 7.62 | 32.5 | 113. | .544E-02 | .111E+03 | .221E+03 | 12.69 | |
| 6 | 10.16 | 31.7 | 119. | .573E-02 | .117E+03 | .233E+03 | 9.99 | X_{max} |
| 7 | 11.43 | 31.9 | 111. | .535E-02 | .109E+03 | .218E+03 | 4.32 | |
| 8 | 12.70 | 32.2 | 116. | .559E-02 | .114E+03 | .227E+03 | 12.42 | |
| 9 | 13.97 | 33.0 | 92. | .441E-02 | .897E+02 | .179E+03 | 4.59 | |
| 10 | 15.24 | 33.6 | 91. | .437E-02 | .889E+02 | .178E+03 | 0.27 | |
| 11 | 16.51 | 34.2 | 86. | .413E-02 | .841E+02 | .168E+03 | 0.81 | |
| 12 | 17.78 | 34.8 | 82. | .395E-02 | .804E+02 | .161E+03 | 0.81 | |
| 13 | 20.32 | 35.8 | 75. | .362E-02 | .737E+02 | .147E+03 | 1.71 | |
| 14 | 25.40 | 37.2 | 70. | .334E-02 | .680E+02 | .136E+03 | 0.67 | |
| 15 | 30.48 | 38.1 | 66. | .315E-02 | .641E+02 | .128E+03 | 0.53 | |
| 16 | 40.64 | 39.0 | 62. | .299E-02 | .609E+02 | .122E+03 | 0.11 | |
| 17 | 50.80 | 39.7 | 60. | .289E-02 | .587E+02 | .117E+03 | 0.00 | |
| 18 | 63.50 | 40.5 | 57. | .276E-02 | .561E+02 | .112E+03 | 0.13 | |
| 19 | 76.20 | 40.9 | 56. | .271E-02 | .551E+02 | .110E+03 | 0.04 | |
| 20 | 88.90 | 41.1 | 56. | .268E-02 | .546E+02 | .109E+03 | 0.05 | |
| 21 | 101.60 | 41.1 | 56. | .268E-02 | .546E+02 | .109E+03 | 0.00 | |

Table A.103: 2 in. cylinder with $S=1$ in.; $U = 17.4(m/s)$, $T = 21.8(^{\circ}C)$,
 $q = 1073(W/m^2)$, $i = 330.0(A)$

Case: 2twa-15a

Date and time of experiment: Aug.22,1992, 12:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|--------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 38.2 | | | | | | |
| 2 | 2.54 | 36.9 | 63. | .339E-02 | .612E+02 | .122E+03 | 0.55 | |
| 3 | 5.08 | 34.2 | 80. | .433E-02 | .782E+02 | .156E+03 | 4.49 | |
| 4 | 6.35 | 33.1 | 90. | .487E-02 | .880E+02 | .176E+03 | 6.24 | |
| 5 | 7.62 | 32.2 | 103. | .559E-02 | .101E+03 | .202E+03 | 11.06 | |
| 6 | 10.16 | 31.4 | 114. | .619E-02 | .112E+03 | .223E+03 | 12.15 | X_{max} |
| 7 | 11.43 | 31.5 | 103. | .555E-02 | .100E+03 | .200E+03 | 2.30 | |
| 8 | 12.70 | 31.7 | 113. | .614E-02 | .111E+03 | .221E+03 | 15.76 | |
| 9 | 13.97 | 32.4 | 86. | .467E-02 | .842E+02 | .168E+03 | 5.25 | |
| 10 | 15.24 | 32.9 | 87. | .470E-02 | .848E+02 | .170E+03 | 0.66 | |
| 11 | 16.51 | 33.5 | 79. | .427E-02 | .771E+02 | .154E+03 | 3.61 | |
| 12 | 17.78 | 33.9 | 80. | .431E-02 | .777E+02 | .155E+03 | 1.20 | |
| 13 | 20.32 | 34.9 | 71. | .384E-02 | .693E+02 | .139E+03 | 1.89 | |
| 14 | 25.40 | 36.2 | 65. | .351E-02 | .634E+02 | .127E+03 | 0.74 | |
| 15 | 30.48 | 37.1 | 61. | .329E-02 | .593E+02 | .119E+03 | 0.64 | |
| 16 | 40.64 | 38.1 | 57. | .310E-02 | .560E+02 | .112E+03 | 0.17 | |
| 17 | 50.80 | 38.7 | 55. | .299E-02 | .540E+02 | .108E+03 | 0.00 | |
| 18 | 63.50 | 39.4 | 53. | .286E-02 | .516E+02 | .103E+03 | 0.16 | |
| 19 | 76.20 | 39.7 | 52. | .282E-02 | .508E+02 | .102E+03 | 0.05 | |
| 20 | 88.90 | 39.8 | 52. | .280E-02 | .505E+02 | .101E+03 | 0.03 | |
| 21 | 101.60 | 39.8 | 52. | .279E-02 | .504E+02 | .101E+03 | 0.01 | |

Table A.104: 2 in. cylinder with $S=1$ in.; $U = 15.3(m/s)$, $T = 22.7(^{\circ}C)$,
 $q = 882(W/m^2)$, $i = 300.0(A)$

Case: 2twa-15b

Date and time of experiment: Sep.7,1992, 12:30

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|--------|-------|------|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 40.7 | | | | | | |
| 2 | 2.54 | 38.8 | 59. | .329E-02 | .577E+02 | .115E+03 | 5.34 | |
| 3 | 5.08 | 35.3 | 77. | .428E-02 | .751E+02 | .150E+03 | 8.83 | |
| 4 | 6.35 | 34.0 | 80. | .443E-02 | .777E+02 | .155E+03 | 1.54 | |
| 5 | 7.62 | 32.7 | 101. | .565E-02 | .991E+02 | .198E+03 | 16.02 | |
| 6 | 10.16 | 31.8 | 108. | .600E-02 | .105E+03 | .211E+03 | 12.53 | X _{max} |
| 7 | 11.43 | 31.9 | 99. | .552E-02 | .968E+02 | .194E+03 | 4.93 | |
| 8 | 12.70 | 32.2 | 104. | .581E-02 | .102E+03 | .204E+03 | 13.87 | |
| 9 | 13.97 | 33.0 | 81. | .452E-02 | .793E+02 | .159E+03 | 4.93 | |
| 10 | 15.24 | 33.6 | 81. | .453E-02 | .794E+02 | .159E+03 | 0.31 | |
| 11 | 16.51 | 34.2 | 76. | .425E-02 | .746E+02 | .149E+03 | 0.92 | |
| 12 | 17.78 | 34.8 | 73. | .407E-02 | .713E+02 | .143E+03 | 0.82 | |
| 13 | 20.32 | 35.8 | 67. | .372E-02 | .652E+02 | .130E+03 | 1.82 | |
| 14 | 25.40 | 37.2 | 61. | .341E-02 | .598E+02 | .120E+03 | 0.87 | |
| 15 | 30.48 | 38.2 | 58. | .321E-02 | .564E+02 | .113E+03 | 0.62 | |
| 16 | 40.64 | 39.1 | 55. | .305E-02 | .535E+02 | .107E+03 | 0.13 | |
| 17 | 50.80 | 39.8 | 53. | .294E-02 | .515E+02 | .103E+03 | 0.00 | |
| 18 | 63.50 | 40.6 | 50. | .280E-02 | .492E+02 | .984E+02 | 0.15 | |
| 19 | 76.20 | 41.0 | 49. | .276E-02 | .483E+02 | .967E+02 | 0.05 | |
| 20 | 88.90 | 41.1 | 49. | .273E-02 | .479E+02 | .958E+02 | 0.06 | |
| 21 | 101.60 | 41.1 | 49. | .273E-02 | .480E+02 | .959E+02 | 0.00 | |

Table A.105: 2 in. cylinder with S=1 in.; $U = 15.0(m/s)$, $T = 22.0(^{\circ}C)$, $q = 940(W/m^2)$, $i = 310.0(A)$

Case: 2twa-12.5

Date and time of experiment: Aug.22,1992, 17:30

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|--------|-------|------|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 42.2 | | | | | | |
| 2 | 2.54 | 40.9 | 43. | .291E-02 | .423E+02 | .845E+02 | 12.05 | |
| 3 | 5.08 | 37.4 | 66. | .447E-02 | .648E+02 | .130E+03 | 6.67 | |
| 4 | 6.35 | 35.9 | 71. | .476E-02 | .690E+02 | .138E+03 | 1.05 | |
| 5 | 7.62 | 34.5 | 96. | .647E-02 | .938E+02 | .188E+03 | 20.48 | |
| 6 | 10.16 | 33.4 | 102. | .690E-02 | .100E+03 | .200E+03 | 14.63 | X_{max} |
| 7 | 11.43 | 33.4 | 94. | .636E-02 | .923E+02 | .185E+03 | 6.32 | |
| 8 | 12.70 | 33.7 | 101. | .682E-02 | .989E+02 | .198E+03 | 16.85 | |
| 9 | 13.97 | 34.4 | 76. | .512E-02 | .742E+02 | .148E+03 | 5.62 | |
| 10 | 15.24 | 35.0 | 77. | .518E-02 | .751E+02 | .150E+03 | 0.70 | |
| 11 | 16.51 | 35.5 | 73. | .490E-02 | .710E+02 | .142E+03 | 0.35 | |
| 12 | 17.78 | 36.1 | 68. | .459E-02 | .665E+02 | .133E+03 | 1.17 | |
| 13 | 20.32 | 37.2 | 62. | .417E-02 | .605E+02 | .121E+03 | 1.96 | |
| 14 | 25.40 | 38.7 | 56. | .378E-02 | .549E+02 | .110E+03 | 0.97 | |
| 15 | 30.48 | 39.8 | 52. | .353E-02 | .513E+02 | .103E+03 | 0.82 | |
| 16 | 40.64 | 40.7 | 50. | .335E-02 | .485E+02 | .971E+02 | 0.18 | |
| 17 | 50.80 | 41.4 | 48. | .323E-02 | .468E+02 | .936E+02 | 0.01 | |
| 18 | 63.50 | 42.2 | 46. | .308E-02 | .447E+02 | .893E+02 | 0.19 | |
| 19 | 76.20 | 42.4 | 45. | .304E-02 | .441E+02 | .882E+02 | 0.03 | |
| 20 | 88.90 | 42.6 | 45. | .301E-02 | .437E+02 | .873E+02 | 0.08 | |
| 21 | 101.60 | 42.6 | 45. | .302E-02 | .438E+02 | .876E+02 | 0.02 | |

Table A.106: 2 in. cylinder with $S=1$ in.; $U = 12.4(m/s)$, $T = 24.2(^{\circ}C)$, $q = 825(W/m^2)$, $i = 290.0(A)$

Case: 2twa-10

Date and time of experiment: Aug.22,1992, 18:20

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|--------|-------|-----|----------|-----------------|-----------------|-------|------------------------|
| 1 | 1.27 | 42.6 | | | | | | |
| 2 | 2.54 | 41.2 | 41. | .344E-02 | .398E+02 | .796E+02 | 5.63 | |
| 3 | 5.08 | 37.9 | 55. | .467E-02 | .540E+02 | .108E+03 | 2.95 | |
| 4 | 6.35 | 36.4 | 61. | .518E-02 | .600E+02 | .120E+03 | 1.21 | |
| 5 | 7.62 | 34.9 | 86. | .725E-02 | .839E+02 | .168E+03 | 23.73 | |
| 6 | 10.16 | 33.6 | 92. | .779E-02 | .902E+02 | .180E+03 | 17.29 | <i>X_{max}</i> |
| 7 | 11.43 | 33.6 | 84. | .707E-02 | .819E+02 | .164E+03 | 6.84 | |
| 8 | 12.70 | 33.9 | 92. | .776E-02 | .898E+02 | .180E+03 | 19.71 | |
| 9 | 13.97 | 34.5 | 68. | .570E-02 | .659E+02 | .132E+03 | 5.63 | |
| 10 | 15.24 | 35.1 | 68. | .575E-02 | .665E+02 | .133E+03 | 0.40 | |
| 11 | 16.51 | 35.6 | 66. | .557E-02 | .645E+02 | .129E+03 | 2.41 | |
| 12 | 17.78 | 36.3 | 60. | .506E-02 | .586E+02 | .117E+03 | 1.74 | |
| 13 | 20.32 | 37.4 | 55. | .461E-02 | .534E+02 | .107E+03 | 1.98 | |
| 14 | 25.40 | 39.0 | 49. | .413E-02 | .478E+02 | .957E+02 | 1.18 | |
| 15 | 30.48 | 40.2 | 45. | .383E-02 | .444E+02 | .887E+02 | 1.01 | |
| 16 | 40.64 | 41.3 | 43. | .361E-02 | .418E+02 | .835E+02 | 0.27 | |
| 17 | 50.80 | 42.0 | 41. | .347E-02 | .402E+02 | .805E+02 | 0.01 | |
| 18 | 63.50 | 42.8 | 39. | .331E-02 | .383E+02 | .767E+02 | 0.23 | |
| 19 | 76.20 | 43.1 | 39. | .327E-02 | .378E+02 | .757E+02 | 0.04 | |
| 20 | 88.90 | 43.2 | 38. | .324E-02 | .375E+02 | .749E+02 | 0.09 | |
| 21 | 101.60 | 43.2 | 38. | .325E-02 | .376E+02 | .752E+02 | 0.02 | |

Table A.107: 2 in. cylinder with S=1 in.; $U = 9.9(m/s)$, $T = 24.5(^{\circ}C)$,
 $q = 720(W/m^2)$, $i = 270.0(A)$

Case: 2twa-8.7

Date and time of experiment: Sep.7,1992, 14:30

| No. | X(cm) | T(°C) | h | St | Nu_s | Nu_d | cond% | |
|-----|--------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 38.0 | | | | | | |
| 2 | 2.54 | 37.6 | 36. | .350E-02 | .356E+02 | .712E+02 | 15.46 | |
| 3 | 5.08 | 35.7 | 47. | .452E-02 | .460E+02 | .921E+02 | 5.36 | |
| 4 | 6.35 | 34.6 | 53. | .513E-02 | .522E+02 | .104E+03 | 2.37 | |
| 5 | 7.62 | 33.4 | 73. | .703E-02 | .715E+02 | .143E+03 | 19.71 | |
| 6 | 10.16 | 32.3 | 81. | .779E-02 | .792E+02 | .158E+03 | 18.14 | X_{max} |
| 7 | 11.43 | 32.3 | 72. | .694E-02 | .706E+02 | .141E+03 | 5.68 | |
| 8 | 12.70 | 32.5 | 80. | .771E-02 | .785E+02 | .157E+03 | 19.40 | |
| 9 | 13.97 | 33.0 | 62. | .597E-02 | .608E+02 | .122E+03 | 1.89 | |
| 10 | 15.24 | 33.6 | 60. | .578E-02 | .588E+02 | .118E+03 | 0.00 | |
| 11 | 16.51 | 34.1 | 58. | .552E-02 | .562E+02 | .112E+03 | 0.47 | |
| 12 | 17.78 | 34.6 | 54. | .521E-02 | .530E+02 | .106E+03 | 0.47 | |
| 13 | 20.32 | 35.6 | 49. | .470E-02 | .478E+02 | .957E+02 | 1.97 | |
| 14 | 25.40 | 37.2 | 44. | .421E-02 | .428E+02 | .856E+02 | 1.15 | |
| 15 | 30.48 | 38.4 | 40. | .388E-02 | .394E+02 | .789E+02 | 1.19 | |
| 16 | 40.64 | 39.5 | 38. | .363E-02 | .370E+02 | .739E+02 | 0.39 | |
| 17 | 50.80 | 40.1 | 37. | .352E-02 | .358E+02 | .716E+02 | 0.03 | |
| 18 | 63.50 | 40.9 | 35. | .335E-02 | .340E+02 | .681E+02 | 0.26 | |
| 19 | 76.20 | 41.2 | 34. | .330E-02 | .336E+02 | .672E+02 | 0.03 | |
| 20 | 88.90 | 41.4 | 34. | .326E-02 | .332E+02 | .664E+02 | 0.09 | |
| 21 | 101.60 | 41.4 | 34. | .326E-02 | .332E+02 | .664E+02 | 0.00 | |

Table A.10S: 2 in. cylinder with $S=1$ in.; $U = 8.7(m/s)$, $T = 23.4(^{\circ}C)$,
 $q = 612(W/m^2)$, $i = 250.0(A)$

Case: 2twa-7.5a

Date and time of experiment: Aug.22,1992, 19:30

| No. | X(cm) | T(°C) | h | St | Nu _s | Nu _d | cond% | |
|-----|--------|-------|-----|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 42.4 | | | | | | |
| 2 | 2.54 | 41.3 | 29. | .326E-02 | .286E+02 | .572E+02 | 11.12 | |
| 3 | 5.08 | 38.4 | 39. | .434E-02 | .381E+02 | .762E+02 | 1.54 | |
| 4 | 6.35 | 36.9 | 43. | .480E-02 | .421E+02 | .842E+02 | 2.57 | |
| 5 | 7.62 | 35.4 | 65. | .725E-02 | .636E+02 | .127E+03 | 29.44 | |
| 6 | 10.16 | 34.1 | 68. | .753E-02 | .661E+02 | .132E+03 | 18.14 | |
| 7 | 11.43 | 33.9 | 69. | .770E-02 | .676E+02 | .135E+03 | 19.00 | X _{max} |
| 8 | 12.70 | 34.1 | 65. | .727E-02 | .638E+02 | .128E+03 | 14.89 | |
| 9 | 13.97 | 34.6 | 53. | .596E-02 | .523E+02 | .105E+03 | 1.03 | |
| 10 | 15.24 | 35.1 | 52. | .581E-02 | .510E+02 | .102E+03 | 1.03 | |
| 11 | 16.51 | 35.6 | 51. | .566E-02 | .497E+02 | .993E+02 | 3.08 | |
| 12 | 17.78 | 36.2 | 47. | .518E-02 | .454E+02 | .909E+02 | 1.03 | |
| 13 | 20.32 | 37.3 | 42. | .470E-02 | .412E+02 | .824E+02 | 2.14 | |
| 14 | 25.40 | 38.9 | 38. | .420E-02 | .369E+02 | .737E+02 | 1.38 | |
| 15 | 30.48 | 40.2 | 35. | .388E-02 | .340E+02 | .681E+02 | 1.33 | |
| 16 | 40.64 | 41.4 | 33. | .364E-02 | .319E+02 | .638E+02 | 0.41 | |
| 17 | 50.80 | 42.1 | 31. | .351E-02 | .308E+02 | .615E+02 | 0.03 | |
| 18 | 63.50 | 42.9 | 30. | .334E-02 | .293E+02 | .587E+02 | 0.27 | |
| 19 | 76.20 | 43.2 | 30. | .330E-02 | .289E+02 | .579E+02 | 0.08 | |
| 20 | 88.90 | 43.4 | 29. | .327E-02 | .287E+02 | .574E+02 | 0.12 | |
| 21 | 101.60 | 43.3 | 30. | .329E-02 | .289E+02 | .577E+02 | 0.04 | |

Table A.109: 2 in. cylinder with S=1 in.; $U = 7.5(m/s)$, $T = 24.2(^{\circ}C)$,
 $q = 564(W/m^2)$, $i = 240.0(A)$

Case: 2twa-7.5b

Date and time of experiment: Sep.7,1992, 14:45

| No. | X(cm) | T(°C) | h | St | Nu_S | Nu_d | cond% | |
|-----|--------|-------|-----|----------|----------|----------|-------|-----------|
| 1 | 1.27 | 38.9 | | | | | | |
| 2 | 2.54 | 38.2 | 31. | .349E-02 | .302E+02 | .604E+02 | 15.44 | |
| 3 | 5.08 | 36.0 | 41. | .460E-02 | .398E+02 | .795E+02 | 5.27 | |
| 4 | 6.35 | 34.8 | 46. | .524E-02 | .453E+02 | .907E+02 | 2.73 | |
| 5 | 7.62 | 33.5 | 68. | .768E-02 | .665E+02 | .133E+03 | 26.16 | |
| 6 | 10.16 | 32.4 | 71. | .799E-02 | .691E+02 | .138E+03 | 16.35 | |
| 7 | 11.43 | 32.3 | 72. | .809E-02 | .700E+02 | .140E+03 | 16.35 | X_{max} |
| 8 | 12.70 | 32.5 | 70. | .788E-02 | .682E+02 | .136E+03 | 15.80 | |
| 9 | 13.97 | 33.0 | 57. | .638E-02 | .552E+02 | .110E+03 | 1.09 | |
| 10 | 15.24 | 33.4 | 56. | .628E-02 | .544E+02 | .109E+03 | 2.18 | |
| 11 | 16.51 | 33.9 | 53. | .594E-02 | .514E+02 | .103E+03 | 1.64 | |
| 12 | 17.78 | 34.5 | 49. | .550E-02 | .476E+02 | .952E+02 | 1.09 | |
| 13 | 20.32 | 35.5 | 44. | .499E-02 | .432E+02 | .864E+02 | 1.95 | |
| 14 | 25.40 | 37.0 | 39. | .443E-02 | .384E+02 | .767E+02 | 1.33 | |
| 15 | 30.48 | 38.2 | 36. | .407E-02 | .352E+02 | .705E+02 | 1.34 | |
| 16 | 40.64 | 39.4 | 34. | .380E-02 | .329E+02 | .658E+02 | 0.45 | |
| 17 | 50.80 | 40.0 | 32. | .367E-02 | .317E+02 | .635E+02 | 0.01 | |
| 18 | 63.50 | 40.9 | 31. | .348E-02 | .301E+02 | .602E+02 | 0.29 | |
| 19 | 76.20 | 41.2 | 30. | .343E-02 | .297E+02 | .593E+02 | 0.07 | |
| 20 | 88.90 | 41.3 | 30. | .339E-02 | .294E+02 | .587E+02 | 0.10 | |
| 21 | 101.60 | 41.3 | 30. | .340E-02 | .294E+02 | .589E+02 | 0.01 | |

Table A.110: 2 in. cylinder with $S=1$ in.; $U = 7.4(m/s)$, $T = 23.7(^{\circ}C)$,
 $q = 532(W/m^2)$, $i = 233.3(A)$

Case: 2twa-06

Date and time of experiment: Sep.7,1992, 15:30

| No. | X(cm) | T(°C) | h | St | Nu _s | Nu _d | cond% | |
|-----|--------|-------|-----|----------|-----------------|-----------------|-------|------------------|
| 1 | 1.27 | 37.8 | | | | | | |
| 2 | 2.54 | 37.1 | 25. | .342E-02 | .244E+02 | .488E+02 | 15.49 | |
| 3 | 5.08 | 35.0 | 34. | .460E-02 | .328E+02 | .657E+02 | 4.50 | |
| 4 | 6.35 | 33.9 | 37. | .509E-02 | .363E+02 | .727E+02 | 5.25 | |
| 5 | 7.62 | 32.6 | 59. | .813E-02 | .580E+02 | .116E+03 | 32.72 | |
| 6 | 10.16 | 31.5 | 62. | .845E-02 | .603E+02 | .121E+03 | 20.23 | |
| 7 | 11.43 | 31.4 | 64. | .873E-02 | .623E+02 | .125E+03 | 21.73 | X _{max} |
| 8 | 12.70 | 31.5 | 60. | .825E-02 | .589E+02 | .118E+03 | 17.23 | |
| 9 | 13.97 | 31.9 | 48. | .661E-02 | .472E+02 | .943E+02 | 1.50 | |
| 10 | 15.24 | 32.3 | 49. | .667E-02 | .476E+02 | .951E+02 | 3.75 | |
| 11 | 16.51 | 32.6 | 46. | .631E-02 | .450E+02 | .901E+02 | 3.00 | |
| 12 | 17.78 | 33.1 | 42. | .580E-02 | .414E+02 | .828E+02 | 0.50 | |
| 13 | 20.32 | 33.9 | 38. | .522E-02 | .372E+02 | .744E+02 | 2.06 | |
| 14 | 25.40 | 35.3 | 34. | .461E-02 | .329E+02 | .657E+02 | 1.45 | |
| 15 | 30.48 | 36.4 | 31. | .420E-02 | .299E+02 | .599E+02 | 1.64 | |
| 16 | 40.64 | 37.5 | 28. | .389E-02 | .278E+02 | .556E+02 | 0.56 | |
| 17 | 50.80 | 38.2 | 27. | .374E-02 | .267E+02 | .534E+02 | 0.05 | |
| 18 | 63.50 | 38.9 | 26. | .355E-02 | .253E+02 | .506E+02 | 0.34 | |
| 19 | 76.20 | 39.2 | 25. | .349E-02 | .249E+02 | .498E+02 | 0.10 | |
| 20 | 88.90 | 39.3 | 25. | .346E-02 | .247E+02 | .494E+02 | 0.13 | |
| 21 | 101.60 | 39.3 | 25. | .348E-02 | .248E+02 | .496E+02 | 0.03 | |

Table A.111: 2 in. cylinder with S=1 in.; $U = 6.1(m/s)$, $T = 24.0(^{\circ}C)$, $q = 387(W/m^2)$, $i = 200.0(A)$

Case: 2twa-05

Date and time of experiment: Aug.22,1992, 21:00

| No. | X(cm) | T(°C) | h | St | Nu _S | Nu _d | cond% | |
|-----|--------|-------|-----|----------|-----------------|-----------------|-------|-----------------|
| 1 | 1.27 | 40.1 | | | | | | |
| 2 | 2.54 | 39.3 | 22. | .365E-02 | .214E+02 | .427E+02 | 16.70 | |
| 3 | 5.08 | 36.9 | 29. | .491E-02 | .287E+02 | .574E+02 | 5.90 | |
| 4 | 6.35 | 35.6 | 35. | .582E-02 | .340E+02 | .681E+02 | 0.00 | |
| 5 | 7.62 | 34.3 | 54. | .910E-02 | .532E+02 | .106E+03 | 38.08 | |
| 6 | 10.16 | 33.2 | 52. | .867E-02 | .507E+02 | .101E+03 | 17.44 | |
| 7 | 11.43 | 33.1 | 56. | .931E-02 | .544E+02 | .109E+03 | 23.58 | λ_{max} |
| 8 | 12.70 | 33.2 | 53. | .883E-02 | .517E+02 | .103E+03 | 19.16 | |
| 9 | 13.97 | 33.6 | 42. | .704E-02 | .412E+02 | .823E+02 | 0.74 | |
| 10 | 15.24 | 34.0 | 42. | .696E-02 | .407E+02 | .814E+02 | 2.21 | |
| 11 | 16.51 | 34.4 | 42. | .710E-02 | .415E+02 | .830E+02 | 8.84 | |
| 12 | 17.78 | 34.9 | 36. | .601E-02 | .351E+02 | .703E+02 | 2.95 | |
| 13 | 20.32 | 35.9 | 33. | .555E-02 | .325E+02 | .650E+02 | 2.15 | |
| 14 | 25.40 | 37.5 | 30. | .493E-02 | .288E+02 | .576E+02 | 1.38 | |
| 15 | 30.48 | 38.7 | 27. | .448E-02 | .262E+02 | .524E+02 | 1.77 | |
| 16 | 40.64 | 40.1 | 25. | .413E-02 | .241E+02 | .483E+02 | 0.70 | |
| 17 | 50.80 | 40.9 | 24. | .396E-02 | .232E+02 | .463E+02 | 0.06 | |
| 18 | 63.50 | 41.8 | 22. | .374E-02 | .219E+02 | .438E+02 | 0.41 | |
| 19 | 76.20 | 42.1 | 22. | .368E-02 | .215E+02 | .430E+02 | 0.14 | |
| 20 | 88.90 | 42.3 | 22. | .365E-02 | .213E+02 | .427E+02 | 0.17 | |
| 21 | 101.60 | 42.2 | 22. | .367E-02 | .215E+02 | .430E+02 | 0.06 | |

Table A.112: 2 in. cylinder with S=1 in.; $U = 5.0(m/s)$, $T = 24.3(^{\circ}C)$,
 $q = 393(W/m^2)$, $i = 200.0(A)$

A.b Data and Results at the Points of Maximum Heat Transfer, in Different Velocities, and for each of the 7 Cases

The correlated equations are: $Nu_{S,max} = (0.14E+00)Re_S^{0.68E+00}$
or: $Nu_{d,max} = (0.11E+00)Re_d^{0.68E+00}$

Table A.113: .5in. cylinder with 1in. step height: Results for the points of maximum heat transfer rate

| U(m/s) | X_{max} | h | Re_S | Re_d | St | Nu_S | Nu_d | cond |
|--------|-----------|------|---------|---------|----------|----------|----------|------|
| 30.1 | 7.62 | 215. | .49E+05 | .25E+05 | .601E-02 | .210E+03 | .105E+03 | 3.3 |
| 30.1 | 7.62 | 216. | .49E+05 | .25E+05 | .603E-02 | .211E+03 | .105E+03 | 3.3 |
| 27.3 | 7.62 | 191. | .45E+05 | .22E+05 | .591E-02 | .187E+03 | .935E+02 | 3.1 |
| 24.9 | 7.62 | 182. | .41E+05 | .20E+05 | .616E-02 | .178E+03 | .889E+02 | 3.6 |
| 22.6 | 7.62 | 173. | .37E+05 | .19E+05 | .644E-02 | .169E+03 | .843E+02 | 3.7 |
| 19.9 | 7.62 | 155. | .33E+05 | .16E+05 | .657E-02 | .152E+03 | .758E+02 | 3.8 |
| 17.5 | 7.62 | 145. | .29E+05 | .14E+05 | .698E-02 | .142E+03 | .708E+02 | 3.8 |
| 14.9 | 7.62 | 127. | .24E+05 | .12E+05 | .719E-02 | .124E+03 | .622E+02 | 4.4 |
| 14.9 | 7.62 | 129. | .24E+05 | .12E+05 | .728E-02 | .126E+03 | .629E+02 | 4.2 |
| 12.6 | 8.89 | 115. | .21E+05 | .10E+05 | .767E-02 | .112E+03 | .561E+02 | 5.1 |
| 10.0 | 8.89 | 101. | .16E+05 | .82E+04 | .854E-02 | .990E+02 | .495E+02 | 5.6 |
| 8.7 | 8.89 | 91. | .14E+05 | .71E+04 | .882E-02 | .890E+02 | .445E+02 | 6.3 |
| 7.5 | 8.89 | 81. | .12E+05 | .61E+04 | .914E-02 | .795E+02 | .398E+02 | 7.0 |
| 7.5 | 8.89 | 82. | .12E+05 | .62E+04 | .917E-02 | .804E+02 | .402E+02 | 6.6 |
| 6.0 | 8.89 | 71. | .98E+04 | .49E+04 | .992E-02 | .690E+02 | .345E+02 | 7.6 |
| 5.0 | 8.89 | 62. | .82E+04 | .41E+04 | .105E-01 | .610E+02 | .305E+02 | 8.3 |

The correlated equations are: $Nu_{S,max} = (0.18E + 00)Re_S^{0.66E+00}$
 or: $Nu_{d,max} = (0.12E + 00)Re_d^{0.66E+00}$

Table A.114: .5in. cylinder with 4in. step diameter: Results for the points of maximum heat transfer rate

| U(m/s) | X_{max} | h | Re_S | Re_d | St | Nu_S | Nu_d | cond |
|--------|-----------|------|---------|---------|----------|----------|----------|------|
| 30.0 | 12.70 | 195. | .88E+05 | .25E+05 | .538E-02 | .333E+03 | .951E+02 | 1.5 |
| 30.0 | 12.70 | 183. | .87E+05 | .25E+05 | .509E-02 | .313E+03 | .894E+02 | 1.5 |
| 27.4 | 12.70 | 180. | .80E+05 | .23E+05 | .543E-02 | .307E+03 | .877E+02 | 1.6 |
| 24.9 | 12.70 | 168. | .73E+05 | .21E+05 | .559E-02 | .288E+03 | .821E+02 | 1.7 |
| 22.6 | 12.70 | 162. | .66E+05 | .19E+05 | .593E-02 | .277E+03 | .790E+02 | 1.8 |
| 20.0 | 12.70 | 147. | .59E+05 | .17E+05 | .610E-02 | .252E+03 | .720E+02 | 2.0 |
| 17.6 | 12.70 | 137. | .52E+05 | .15E+05 | .643E-02 | .234E+03 | .667E+02 | 2.0 |
| 14.8 | 12.70 | 117. | .43E+05 | .12E+05 | .653E-02 | .200E+03 | .570E+02 | 2.4 |
| 15.0 | 12.70 | 122. | .43E+05 | .12E+05 | .680E-02 | .209E+03 | .596E+02 | 2.3 |
| 12.7 | 12.70 | 109. | .37E+05 | .11E+05 | .709E-02 | .186E+03 | .531E+02 | 2.7 |
| 9.9 | 12.70 | 94. | .29E+05 | .83E+04 | .785E-02 | .160E+03 | .458E+02 | 3.1 |
| 8.7 | 12.70 | 84. | .25E+05 | .72E+04 | .806E-02 | .144E+03 | .410E+02 | 3.2 |
| 7.4 | 12.70 | 75. | .21E+05 | .61E+04 | .845E-02 | .128E+03 | .366E+02 | 3.4 |
| 7.5 | 12.70 | 77. | .22E+05 | .63E+04 | .847E-02 | .131E+03 | .375E+02 | 3.2 |
| 6.0 | 12.70 | 67. | .18E+05 | .50E+04 | .923E-02 | .114E+03 | .326E+02 | 3.8 |
| 5.0 | 12.70 | 58. | .15E+05 | .42E+04 | .969E-02 | .100E+03 | .286E+02 | 4.0 |

The correlated equations are: $Nu_{S,max} = (0.22E+00)Re_S^{0.61E+00}$
 or: $Nu_{d,max} = (0.29E+00)Re_d^{0.61E+00}$

Table A.115: 1in. cylinder with 2in. step diameter: Results for the points of maximum heat transfer rate

| U(m/s) | X_{max} | h | Re_S | Re_d | St | Nu_S | Nu_d | cond |
|--------|-----------|------|---------|---------|----------|----------|----------|------|
| 30.0 | 5.08 | 211. | .24E+05 | .49E+05 | .591E-02 | .103E+03 | .206E+03 | 14.1 |
| 29.9 | 5.08 | 213. | .24E+05 | .49E+05 | .600E-02 | .104E+03 | .208E+03 | 14.4 |
| 27.6 | 5.08 | 199. | .22E+05 | .45E+05 | .607E-02 | .972E+02 | .194E+03 | 15.1 |
| 24.8 | 5.08 | 189. | .20E+05 | .40E+05 | .640E-02 | .921E+02 | .184E+03 | 16.2 |
| 22.4 | 5.08 | 173. | .18E+05 | .36E+05 | .652E-02 | .847E+02 | .169E+03 | 17.2 |
| 20.0 | 5.08 | 166. | .16E+05 | .33E+05 | .698E-02 | .809E+02 | .162E+03 | 18.3 |
| 17.5 | 5.08 | 153. | .14E+05 | .29E+05 | .737E-02 | .747E+02 | .149E+03 | 19.7 |
| 15.0 | 5.08 | 139. | .12E+05 | .24E+05 | .783E-02 | .681E+02 | .136E+03 | 22.4 |
| 15.1 | 5.08 | 137. | .12E+05 | .25E+05 | .762E-02 | .668E+02 | .134E+03 | 22.0 |
| 12.4 | 6.35 | 118. | .10E+05 | .20E+05 | .805E-02 | .579E+02 | .116E+03 | 21.9 |
| 10.1 | 6.35 | 108. | .82E+04 | .16E+05 | .898E-02 | .526E+02 | .105E+03 | 31.0 |
| 8.7 | 6.35 | 96. | .71E+04 | .14E+05 | .927E-02 | .468E+02 | .935E+02 | 27.4 |
| 7.5 | 6.35 | 89. | .61E+04 | .12E+05 | .101E-01 | .437E+02 | .874E+02 | 32.3 |
| 7.5 | 6.35 | 87. | .61E+04 | .12E+05 | .978E-02 | .425E+02 | .851E+02 | 29.3 |
| 6.2 | 6.35 | 79. | .50E+04 | .10E+05 | .108E-01 | .388E+02 | .775E+02 | 40.4 |
| 5.0 | 6.35 | 77. | .41E+04 | .81E+04 | .129E-01 | .374E+02 | .748E+02 | 49.3 |

The correlated equations are: $Nu_{S,max} = (0.12E+00)Re_S^{0.68E+00}$
 or: $Nu_{d,max} = (0.12E+00)Re_d^{0.68E+00}$

Table A.116: lin. cylinder with lin. step height: Results for the points of maximum heat transfer rate

| U(m/s) | X_{max} | h | Re_S | Re_d | St | Nu_S | Nu_d | cond |
|--------|-----------|------|---------|---------|----------|----------|----------|------|
| 30.1 | 8.89 | 195. | .49E+05 | .49E+05 | .545E-02 | .190E+03 | .190E+03 | 6.6 |
| 30.0 | 8.89 | 194. | .49E+05 | .49E+05 | .546E-02 | .190E+03 | .190E+03 | 6.5 |
| 27.7 | 8.89 | 183. | .45E+05 | .45E+05 | .557E-02 | .179E+03 | .179E+03 | 7.0 |
| 25.0 | 8.89 | 172. | .41E+05 | .41E+05 | .578E-02 | .168E+03 | .168E+03 | 7.7 |
| 22.4 | 8.89 | 161. | .36E+05 | .36E+05 | .607E-02 | .158E+03 | .158E+03 | 8.0 |
| 19.9 | 8.89 | 147. | .32E+05 | .32E+05 | .620E-02 | .143E+03 | .143E+03 | 8.8 |
| 17.5 | 8.89 | 134. | .29E+05 | .29E+05 | .644E-02 | .131E+03 | .131E+03 | 9.2 |
| 15.0 | 8.89 | 121. | .24E+05 | .24E+05 | .677E-02 | .118E+03 | .118E+03 | 11.5 |
| 15.2 | 8.89 | 119. | .25E+05 | .25E+05 | .657E-02 | .116E+03 | .116E+03 | 11.5 |
| 12.6 | 8.89 | 106. | .21E+05 | .21E+05 | .707E-02 | .103E+03 | .103E+03 | 12.0 |
| 10.0 | 10.16 | 92. | .16E+05 | .16E+05 | .775E-02 | .899E+02 | .899E+02 | 14.5 |
| 8.8 | 10.16 | 85. | .14E+05 | .14E+05 | .815E-02 | .832E+02 | .832E+02 | 15.5 |
| 7.5 | 10.16 | 76. | .12E+05 | .12E+05 | .856E-02 | .744E+02 | .744E+02 | 17.1 |
| 7.6 | 10.16 | 75. | .12E+05 | .12E+05 | .837E-02 | .737E+02 | .737E+02 | 14.4 |
| 6.0 | 10.16 | 65. | .98E+04 | .98E+04 | .915E-02 | .637E+02 | .637E+02 | 20.5 |
| 5.1 | 10.16 | 58. | .83E+04 | .83E+04 | .955E-02 | .565E+02 | .565E+02 | 19.3 |

The correlated equations are: $Nu_{S,max} = (0.11E+00)Re_S^{0.69E+00}$
 or: $Nu_{d,max} = (0.10E+00)Re_d^{0.69E+00}$

Table A.117: 1in. cylinder with 4in. step diameter: Results for the points of maximum heat transfer rate

| U(m/s) | X_{max} | h | Re_S | Re_d | St | Nu_S | Nu_d | cond |
|--------|-----------|------|---------|---------|----------|----------|----------|------|
| 30.2 | 11.43 | 185. | .73E+05 | .49E+05 | .521E-02 | .271E+03 | .181E+03 | 3.8 |
| 30.0 | 11.43 | 182. | .73E+05 | .48E+05 | .514E-02 | .266E+03 | .177E+03 | 4.5 |
| 27.7 | 11.43 | 171. | .67E+05 | .45E+05 | .525E-02 | .251E+03 | .167E+03 | 4.3 |
| 25.1 | 11.43 | 161. | .61E+05 | .41E+05 | .545E-02 | .236E+03 | .157E+03 | 4.6 |
| 22.6 | 11.43 | 149. | .55E+05 | .37E+05 | .560E-02 | .218E+03 | .146E+03 | 4.6 |
| 20.0 | 11.43 | 138. | .48E+05 | .32E+05 | .587E-02 | .202E+03 | .135E+03 | 5.5 |
| 17.7 | 11.43 | 127. | .43E+05 | .29E+05 | .609E-02 | .186E+03 | .124E+03 | 7.5 |
| 15.0 | 11.43 | 115. | .36E+05 | .24E+05 | .652E-02 | .169E+03 | .112E+03 | 7.0 |
| 15.1 | 11.43 | 111. | .37E+05 | .24E+05 | .625E-02 | .163E+03 | .109E+03 | 10.6 |
| 12.4 | 12.70 | 97. | .30E+05 | .20E+05 | .662E-02 | .143E+03 | .952E+02 | 6.8 |
| 9.9 | 12.70 | 83. | .24E+05 | .16E+05 | .708E-02 | .122E+03 | .813E+02 | 8.4 |
| 8.6 | 12.70 | 80. | .21E+05 | .14E+05 | .779E-02 | .117E+03 | .777E+02 | 10.3 |
| 7.5 | 12.70 | 69. | .18E+05 | .12E+05 | .775E-02 | .101E+03 | .674E+02 | 9.7 |
| 7.5 | 13.97 | 68. | .18E+05 | .12E+05 | .764E-02 | .996E+02 | .664E+02 | 9.1 |
| 5.8 | 13.97 | 59. | .14E+05 | .94E+04 | .863E-02 | .870E+02 | .580E+02 | 13.7 |
| 5.0 | 13.97 | 54. | .12E+05 | .81E+04 | .908E-02 | .789E+02 | .526E+02 | 13.1 |

The correlated equations are: $Nu_{S,max} = (0.15E+00)Re_S^{0.67E+00}$
or: $Nu_{d,max} = (0.12E+00)Re_d^{0.67E+00}$

Table A.118: 1in. cylinder with 5in. step diameter: Results for the points of maximum heat transfer rate

| U(m/s) | X_{max} | h | Re_S | Re_d | St | Nu_S | Nu_d | cond |
|--------|-----------|------|---------|---------|----------|----------|----------|------|
| 29.8 | 15.24 | 172. | .10E+06 | .49E+05 | .483E-02 | .358E+03 | .168E+03 | 2.2 |
| 30.1 | 15.24 | 165. | .11E+06 | .50E+05 | .457E-02 | .342E+03 | .161E+03 | 2.2 |
| 27.3 | 15.24 | 159 | .97E+05 | .45E+05 | .482E-02 | .330E+03 | .155E+03 | 2.3 |
| 25.0 | 15.24 | 152. | .88E+05 | .41E+05 | .509E-02 | .317E+03 | .149E+03 | 2.8 |
| 22.6 | 15.24 | 140. | .80E+05 | .38E+05 | .513E-02 | .291E+03 | .137E+03 | 3.0 |
| 19.9 | 15.24 | 126. | .70E+05 | .33E+05 | .530E-02 | .262E+03 | .123E+03 | 3.3 |
| 17.5 | 15.24 | 116. | .61E+05 | .29E+05 | .554E-02 | .241E+03 | .113E+03 | 4.0 |
| 15.0 | 17.78 | 103. | .53E+05 | .25E+05 | .571E-02 | .215E+03 | .101E+03 | 4.7 |
| 14.8 | 17.78 | 105. | .52E+05 | .24E+05 | .594E-02 | .219E+03 | .103E+03 | 5.4 |
| 12.5 | 17.78 | 106. | .44E+05 | .21E+05 | .704E-02 | .221E+03 | .104E+03 | 14.7 |
| 10.0 | 17.78 | 81. | .35E+05 | .17E+05 | .674E-02 | .169E+03 | .795E+02 | 6.3 |
| 8.7 | 17.78 | 72. | .31E+05 | .14E+05 | .688E-02 | .150E+03 | .706E+02 | 5.6 |
| 7.5 | 17.78 | 64. | .26E+05 | .12E+05 | .716E-02 | .133E+03 | .628E+02 | 6.8 |
| 7.4 | 17.78 | 68. | .26E+05 | .12E+05 | .758E-02 | .141E+03 | .662E+02 | 7.6 |
| 6.0 | 17.78 | 57. | .21E+05 | .10E+05 | .791E-02 | .119E+03 | .560E+02 | 7.7 |
| 5.0 | 17.78 | 51. | .18E+05 | .83E+04 | .851E-02 | .107E+03 | .502E+02 | 8.1 |

The correlated equations are: $Nu_{S,max} = (0.19E+00)Re_S^{0.63E+00}$
 or: $Nu_{d,max} = (0.25E+00)Re_d^{0.63E+00}$

Table A.119: 2in. cylinder: Results for the points of maximum heat transfer rate

| U(m/s) | X_{max} | h | Re_S | Re_d | St | Nu_S | Nu_d | cond |
|--------|-----------|------|---------|---------|----------|----------|----------|------|
| 29.7 | 10.16 | 166. | .49E+05 | .99E+05 | .463E-02 | .162E+03 | .324E+03 | 8.1 |
| 30.0 | 10.16 | 175. | .50E+05 | .99E+05 | .487E-02 | .171E+03 | .342E+03 | 7.5 |
| 27.5 | 10.16 | 169. | .45E+05 | .90E+05 | .513E-02 | .165E+03 | .330E+03 | 7.8 |
| 25.0 | 10.15 | 161. | .42E+05 | .83E+05 | .534E-02 | .157E+03 | .315E+03 | 9.0 |
| 22.4 | 10.16 | 139. | .37E+05 | .74E+05 | .517E-02 | .135E+03 | .271E+03 | 9.0 |
| 20.2 | 10.16 | 138. | .34E+05 | .67E+05 | .566E-02 | .135E+03 | .270E+03 | 10.3 |
| 17.4 | 10.16 | 119. | .29E+05 | .57E+05 | .573E-02 | .117E+03 | .233E+03 | 10.0 |
| 15.3 | 10.16 | 114. | .25E+05 | .51E+05 | .619E-02 | .112E+03 | .223E+03 | 12.2 |
| 15.0 | 10.16 | 108. | .25E+05 | .50E+05 | .600E-02 | .105E+03 | .211E+03 | 12.5 |
| 12.4 | 10.16 | 102. | .20E+05 | .41E+05 | .690E-02 | .100E+03 | .200E+03 | 14.6 |
| 9.9 | 10.16 | 92. | .16E+05 | .33E+05 | .779E-02 | .902E+02 | .180E+03 | 17.3 |
| 8.7 | 10.16 | 81. | .14E+05 | .29E+05 | .779E-02 | .792E+02 | .158E+03 | 18.1 |
| 7.5 | 11.43 | 69. | .12E+05 | .25E+05 | .770E-02 | .676E+02 | .135E+03 | 19.0 |
| 7.4 | 11.43 | 72. | .12E+05 | .24E+05 | .809E-02 | .700E+02 | .140E+03 | 16.4 |
| 6.1 | 11.43 | 64. | .10E+05 | .20E+05 | .873E-02 | .623E+02 | .125E+03 | 21.7 |
| 5.0 | 11.43 | 56. | .82E+04 | .16E+05 | .931E-02 | .544E+02 | .109E+03 | 23.6 |

A.c Tables of X_r , X_{max} , and $cond_{max}\%$ for 7 cases, at $U = 7.5, 15, \text{ and } 30 \text{ m/s}$

| Aspect Ratio: $S/d = 2, D/d = 5$ | | | |
|----------------------------------|-------------|---------------|----------------|
| $U(m/s)$ | $X_r(in.)$ | $X_{max}(in)$ | $Cond_{max}\%$ |
| 30 | 3.25 - 3.50 | 3.0 - 3.5 | 3.3 |
| 15 | 3.25 - 3.50 | 3.0 - 3.5 | 4.3 |
| 7.5 | 3.75 - 4.00 | 3.5 - 4.0 | 7.0 |

Table A.120: $d = .5''$, $D = 2.5''$, $S = 1''$

| Aspect Ratio: $D/d = 8$ | | | |
|-------------------------|-------------|---------------|----------------|
| $U(m/s)$ | $X_r(in.)$ | $X_{max}(in)$ | $Cond_{max}\%$ |
| 30 | 5.00 - 5.25 | 5.0 - 5.5 | 1.5 |
| 15 | 5.25 - 5.50 | 5.0 - 5.5 | 2.4 |
| 7.5 | 5.50 - 5.75 | 5.0 - 5.5 | 3.4 |

Table A.121: $d = .5''$, $D = 4''$, $S = 1.75''$

| Aspect Ratio: $S/d = 0.5, D/d = 2$ | | | |
|------------------------------------|-------------|---------------|----------------|
| $U(m/s)$ | $X_r(in.)$ | $X_{max}(in)$ | $Cond_{max}\%$ |
| 30 | 2.00 - 2.25 | 2.0 - 2.5 | 14. |
| 15 | 2.25 - 2.50 | 2.0 - 2.5 | 22. |
| 7.5 | 2.50 - 2.75 | 2.5 - 3.0 | 35. |

Table A.122: $d = 1''$, $D = 2''$, $S = 0.5''$

| Aspect Ratio: $S/d = 1, D/d = 3$ | | | |
|----------------------------------|-------------|---------------|----------------|
| $U(m/s)$ | $X_r(in.)$ | $X_{max}(in)$ | $Cond_{max}\%$ |
| 30 | 3.75 - 4.00 | 3.5 - 4.0 | 7.7 |
| 15 | 3.75 - 4.00 | 3.5 - 4.0 | 11. |
| 7.5 | 4.25 - 4.50 | 4.0 - 4.5 | 17. |

Table A.123: $d = 1''$, $D = 3''$, $S = 1''$

| Aspect Ratio: $S/d = 1.5, D/d = 4$ | | | |
|------------------------------------|-------------|---------------|----------------|
| $U(m/s)$ | $X_r(in.)$ | $X_{max}(in)$ | $Cond_{max}\%$ |
| 30 | 5.00 - 5.25 | 4.5 - 5.0 | 5.3 |
| 15 | 5.25 - 5.50 | 4.5 - 5.0 | 9.6 |
| 7.5 | 5.75 - 6.00 | 5.0 - 5.5 | 12. |

Table A.124: $d = 1''$, $D = 4''$, $S = 1.5''$

| Aspect Ratio: $S/d = 2, D/d = 5$ | | | |
|----------------------------------|-------------|---------------|----------------|
| $U(m/s)$ | $X_r(in.)$ | $X_{max}(in)$ | $Cond_{max}\%$ |
| 30 | 6.50 - 6.75 | 6.0 - 6.5 | 3.7 |
| 15 | 7.00 - 7.25 | 7.0 - 7.5 | 5.9 |
| 7.5 | 7.25 - 7.50 | 7.0 - 7.5 | 9.8 |

Table A.125: $d = 1''$, $D = 5''$, $S = 2''$

| Aspect Ratio: $S/d = 0.5, D/d = 2$ | | | |
|------------------------------------|-------------|---------------|----------------|
| $U(m/s)$ | $X_r(in.)$ | $X_{max}(in)$ | $Cond_{max}\%$ |
| 30 | 4.00 - 4.25 | 4.0 - 4.5 | 11. |
| 15 | 4.25 - 4.50 | 4.0 - 4.5 | 16. |
| 7.5 | 4.50 - 4.75 | 4.5 - 5.0 | 29. |

Table A.126: $d = 2''$, $D = 4''$, $S = 1''$

Appendix B

Set of Figures

Fixed Step Diameter

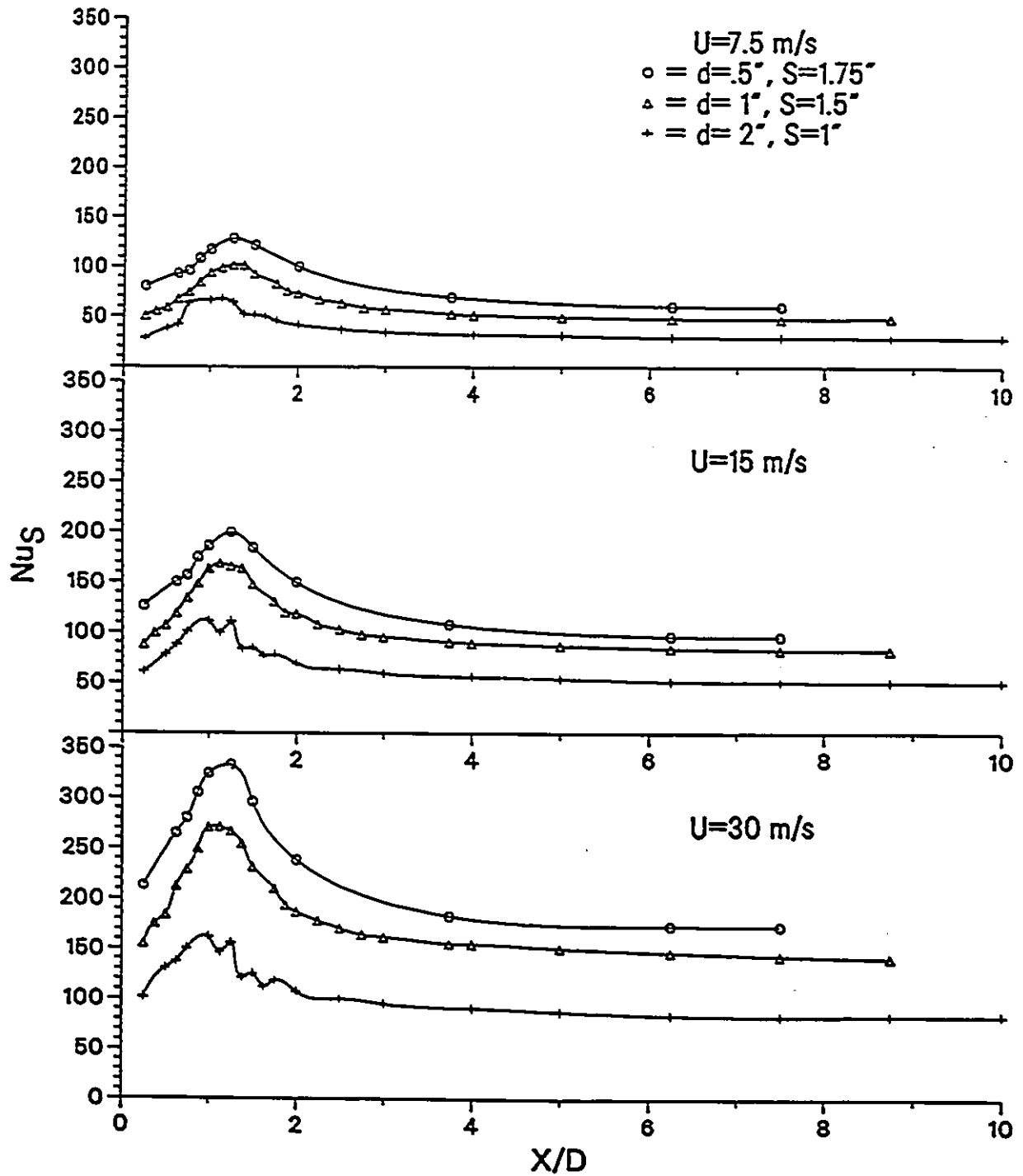


Figure B.1: Effect of transverse convex curvature on heat transfer for the fixed $D = 4''$

Fixed Step Height

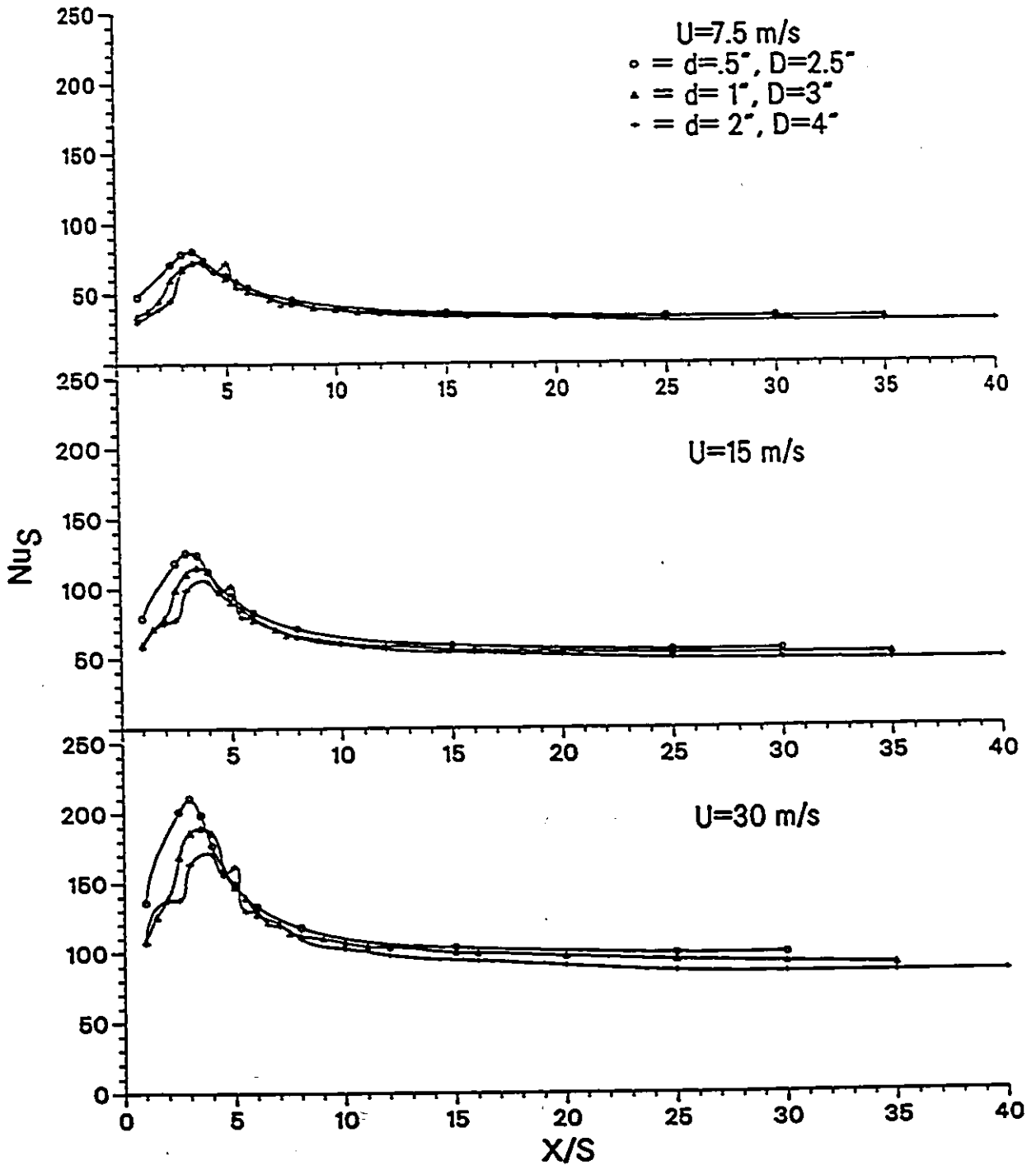


Figure B.2: Effect of transverse convex curvature on heat transfer for the fixed $S = 1''$

REC'D 16 FEB, 1991 JOB-178053, UNIVERSITY OF OTTAWA DISSEMIN 10.5

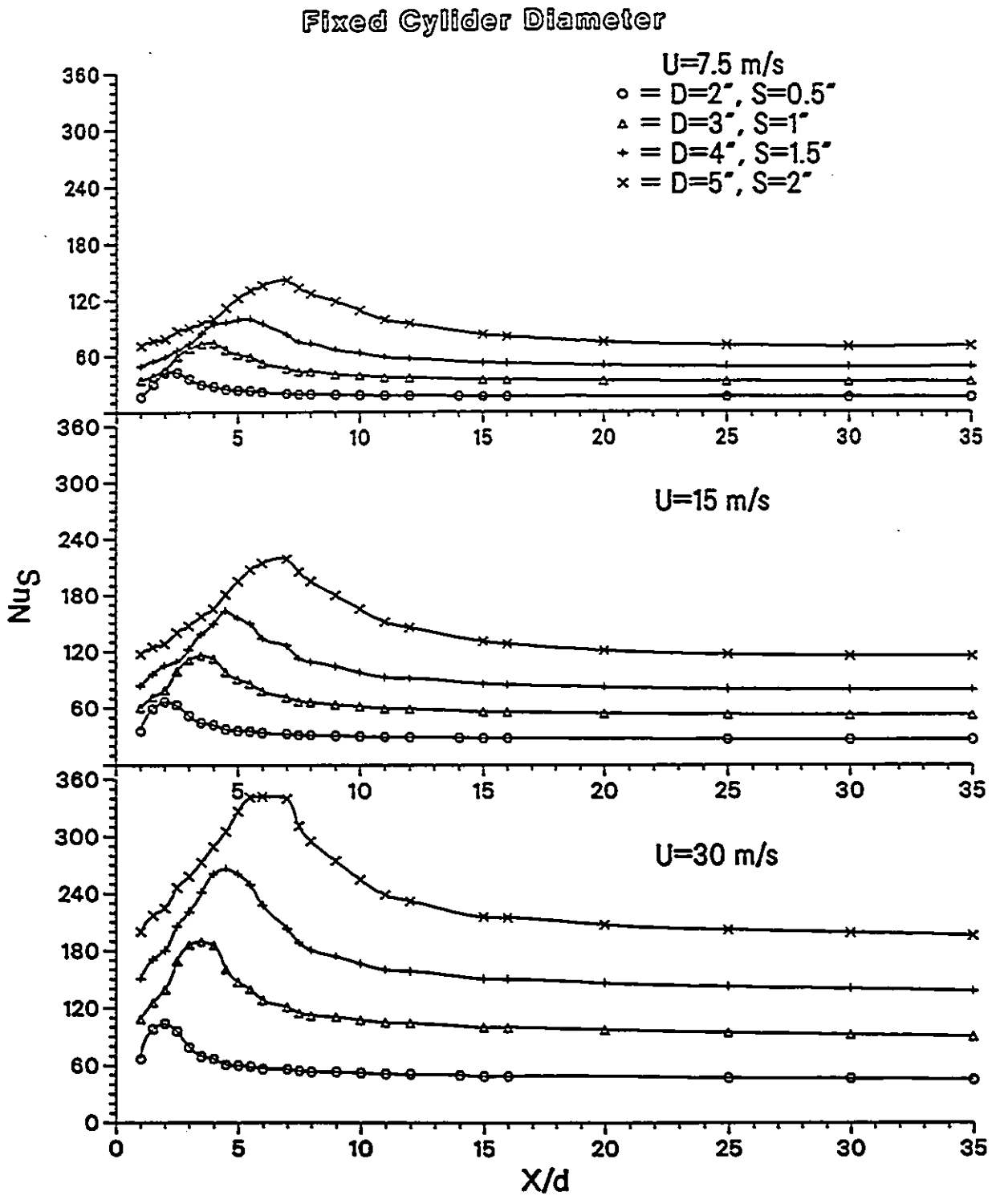


Figure B.3: Effect of step change on heat transfer for the fixed $d = 1"$

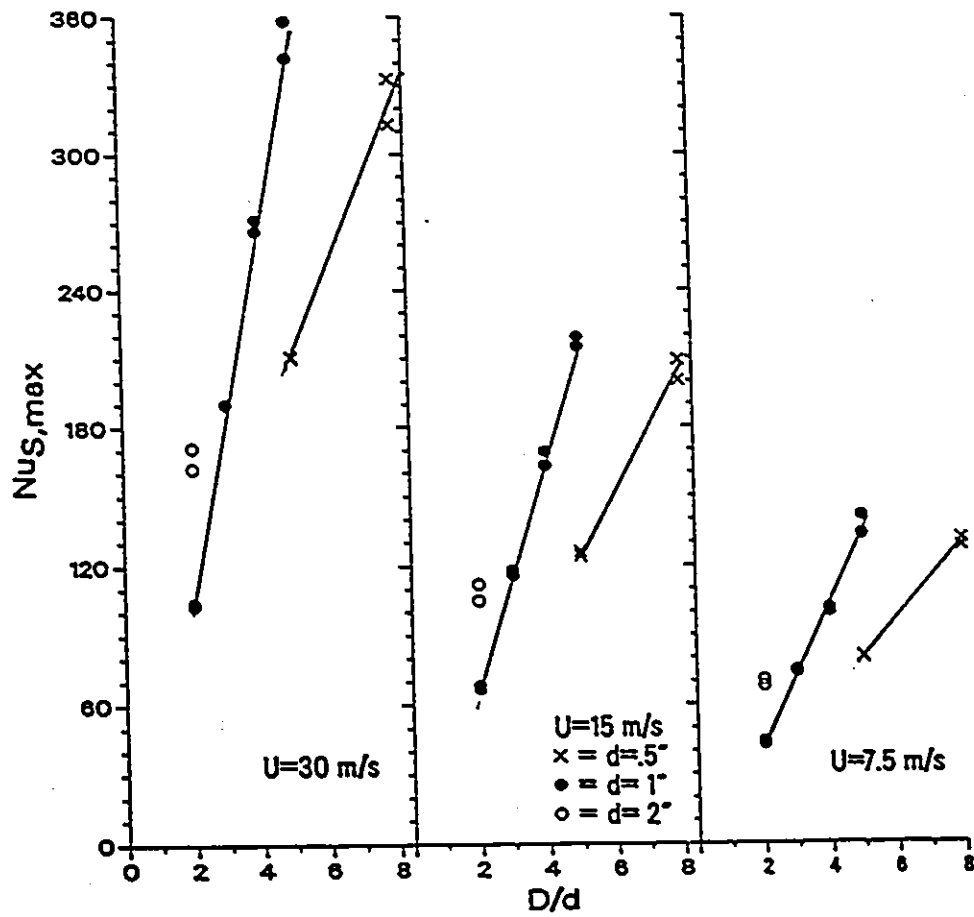


Figure B.4: Effect of aspect ratio (D/d) on maximum heat transfer

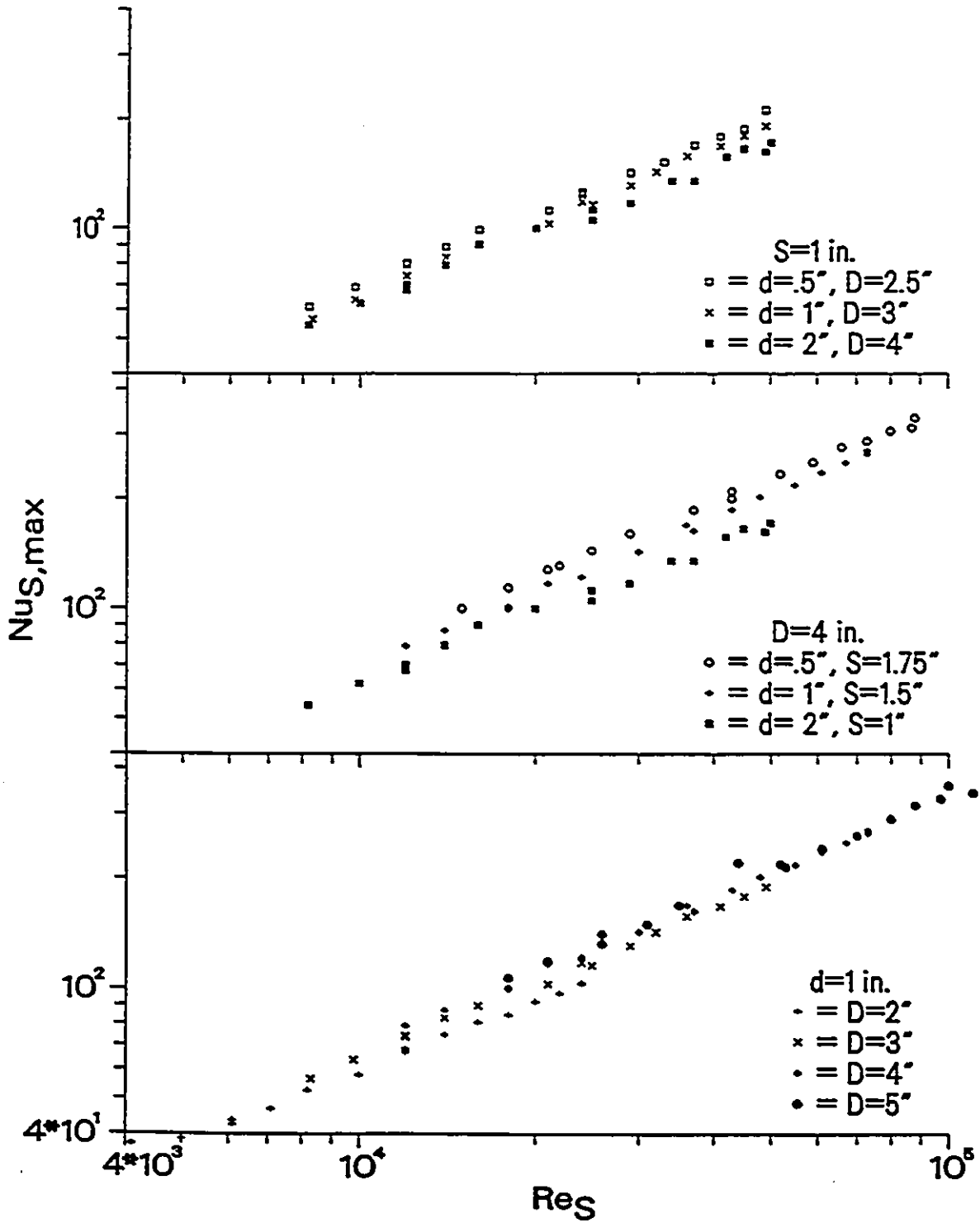


Figure B.5: Scattergram of $Nu_{S,max}$ in three geometrical categories

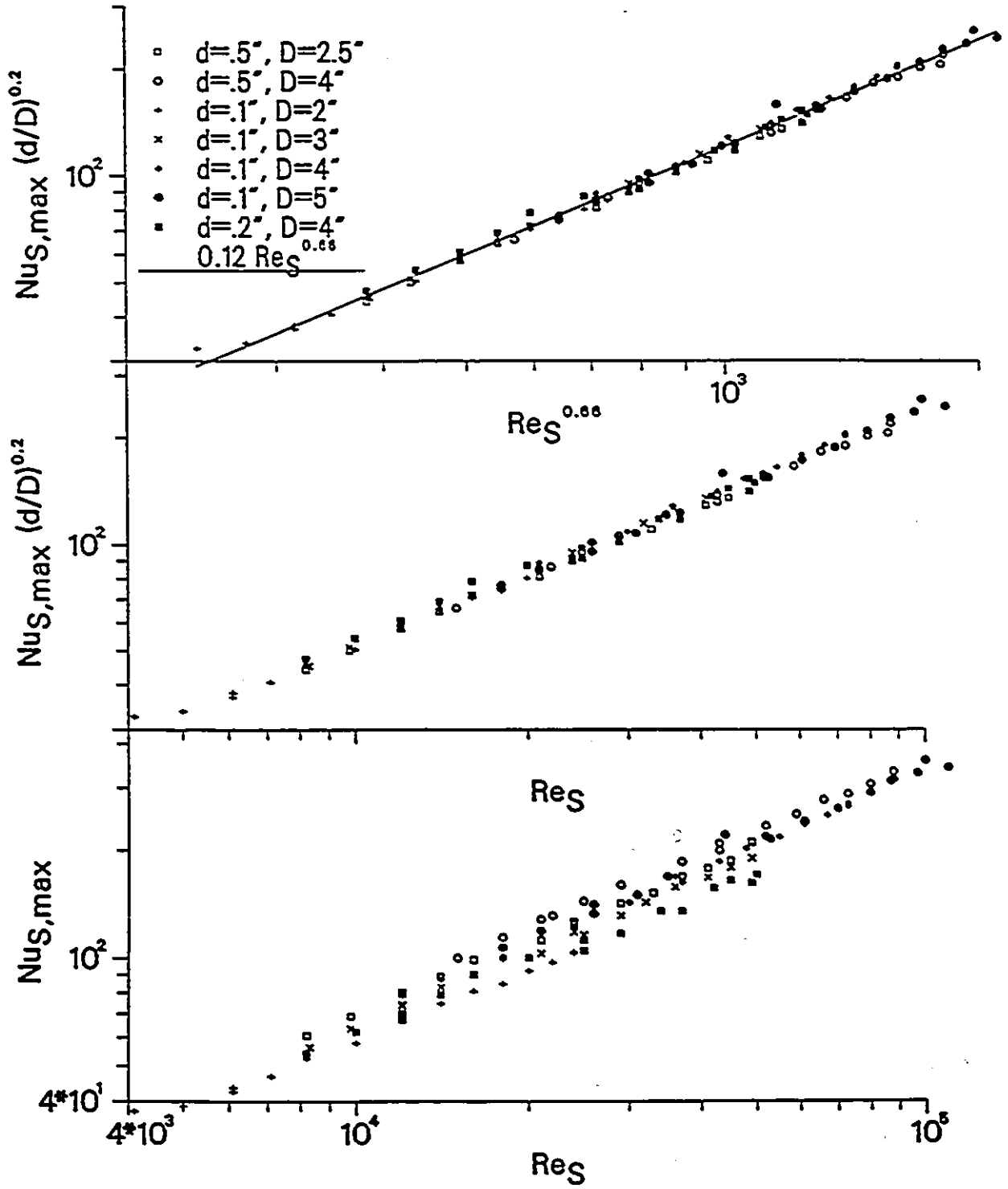


Figure B.6: Overall Scattergram of $Nu_{S,max}$ and its correlation with (d/D) and Re_S

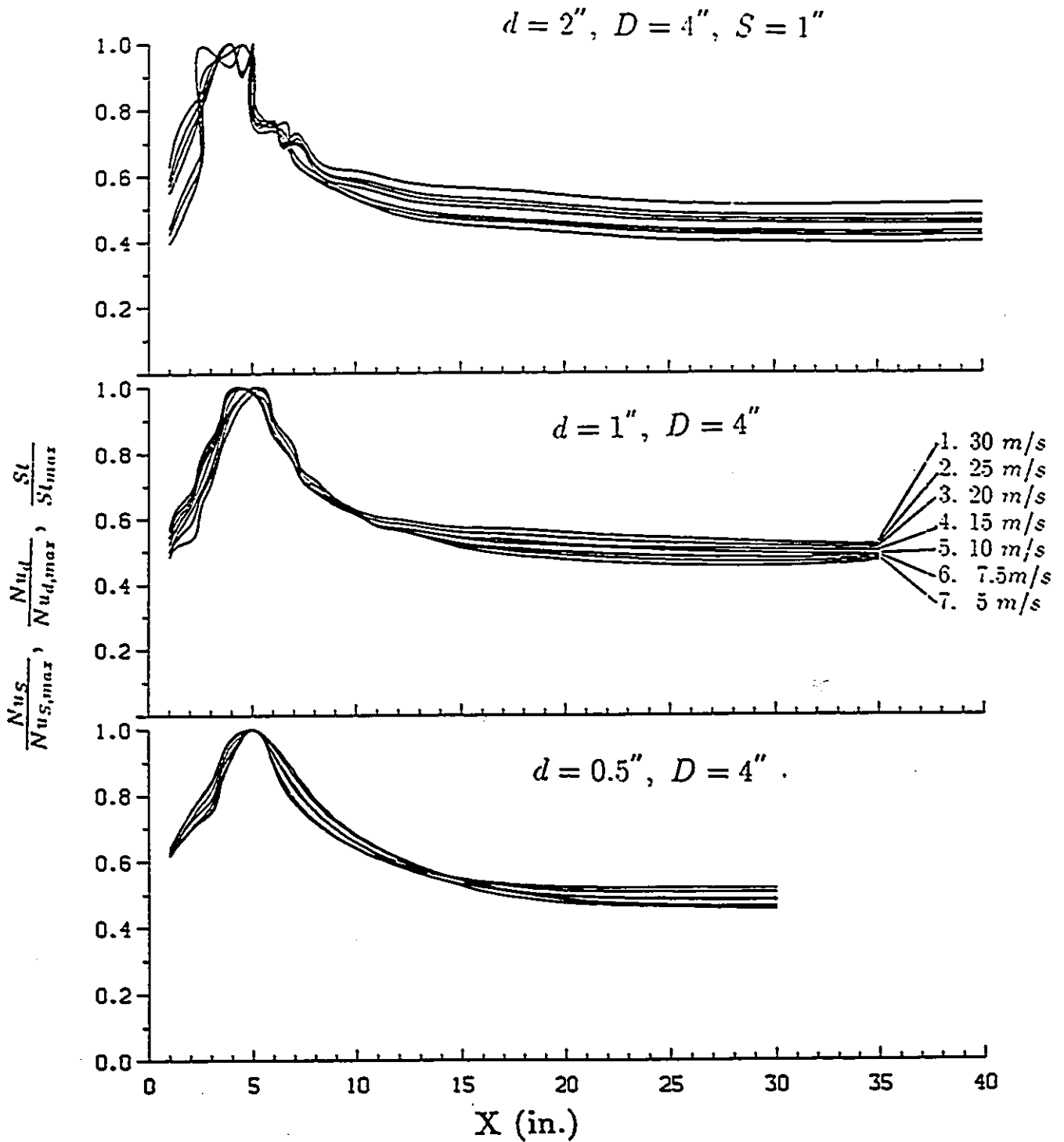


Figure B.7: Comparison of the normalized results for 4" step diameter in three cylinders, each in seven velocity cases

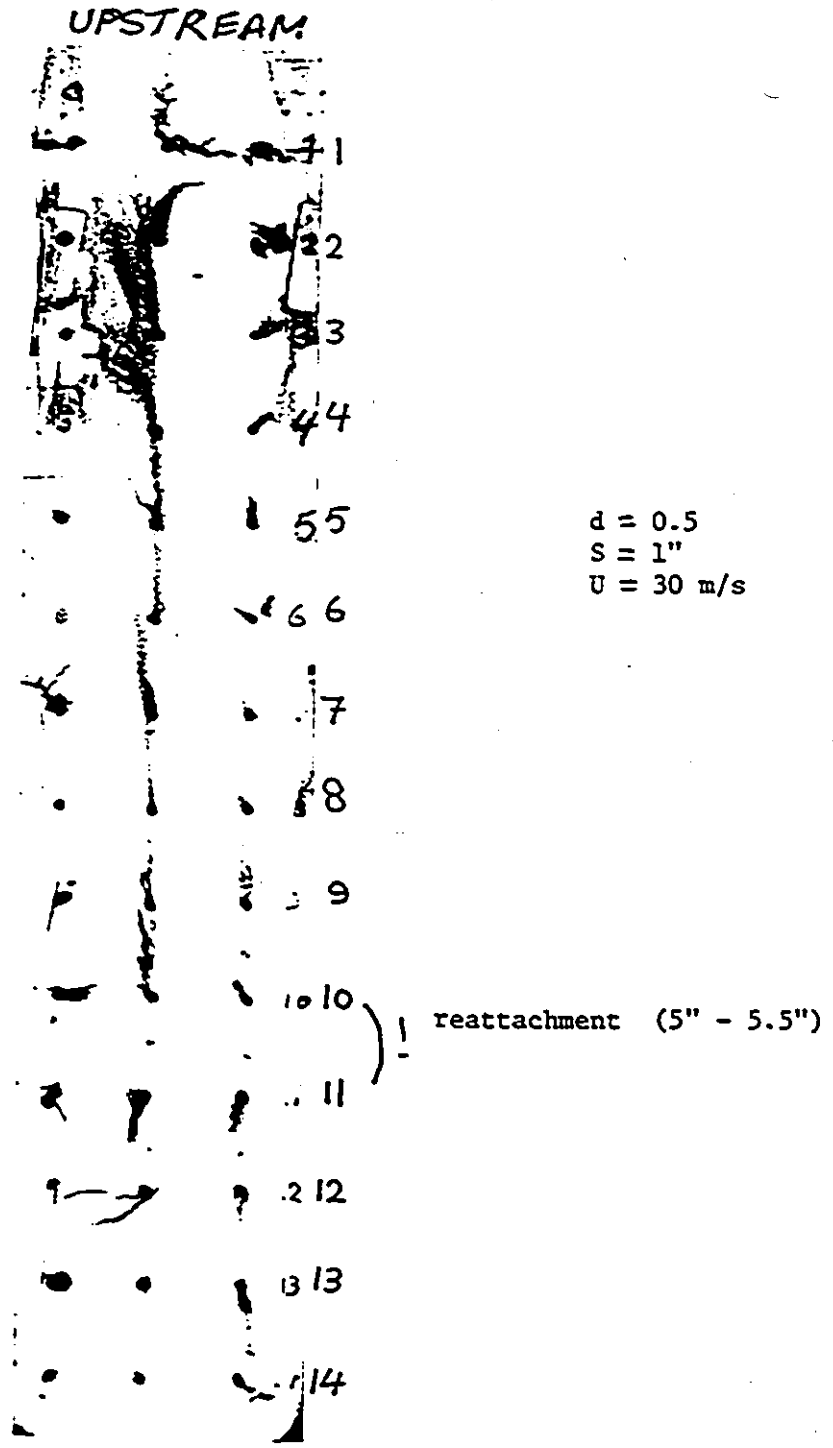


Figure B.8: Flow visualization: Sample of an ink-dot streakline pattern recorded on transparent film

Appendix C

Error Analysis

We would like to estimate the random error for the calculated result of the experiment, on the basis of uncertainty in the primary measurements of the parameters. The experimental uncertainty is estimated by using a standard method presented by Kline and McClintock (1953).

Having R as a function of the independent variables x_1, x_2, \dots, x_n such that:

$$R = R(x_1, x_2, \dots, x_n) \quad (\text{C.1})$$

the uncertainty of the result, w_R , through using uncertainties of each measured variable (w_1, w_2, \dots, w_n) is obtained as follows:

$$w_R = \left[\left(\frac{\partial R}{\partial x_1} w_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} w_2 \right)^2 + \dots + \left(\frac{\partial R}{\partial x_n} w_n \right)^2 \right]^{1/2} \quad (\text{C.2})$$

However, the entire analysis is performed for the test at upstream velocity of 30 m/s on the 2 in. cylinder, and as well for the parameters of $q, \mu, \rho, U, h, Re, St$, and Nu . For the simplicity of calculation, the terms with negligible uncertainty were dropped off.

Heat Flux

The heat flux is obtained from : $q = \frac{i.v}{\pi.d}$

$$\text{Thus, } q = \frac{(333. \pm 2)(0.52 \pm 0.00052)}{\pi(0.0508 \pm 0.0001)} = 1085 \text{ W/m}^2$$

By applying Equation C.2:

$$w_q = \left[\left(2 \frac{v}{\pi d} \right)^2 + \left(0.00052 \frac{i}{\pi d} \right)^2 + \left(-0.0001 \frac{i.v}{\pi d^2} \right)^2 \right]^{1/2} = 6.86, \text{ or } 0.63\% \quad (\text{C.3})$$

While the second term is negligible, the major uncertainty is contributed to the ampere reading.

Temperature

The Section (T) in Omega manual (Omega, 1985) gives the uncertainty of temperature, measured by thermocouple, $\pm 0.8^\circ\text{C}$, while the random error of room temperature, by thermometer, may be given as $\pm 0.5^\circ\text{C}$.

Upstream Velocity

The velocity was measured using a pressure transducer with not more than 0.1% resolution at full scale, which was connected to a voltmeter with 0.0001% of uncertainty. The following equation was fed into the data acquisition system for converting the voltage signals received from the pressure transducer into the velocity magnitudes:

$$U = \sqrt{2g \frac{\rho_{Hg}}{\rho_{air}} \frac{\text{volt}}{10}} \quad (\text{C.4})$$

which gives $U = \sqrt{(2(9.807) \frac{13521}{1.19} (0.404))} / 10 = 30.0 \text{ m/s}$.

The decisive cause of uncertainty is ρ_{air} , which is calculated in the data

acquisition system by the following equations:

$$P_{atm} = \rho_{Hg}(9.807)(\text{barometer reading}) \quad (C.5)$$

$$P_{atm} = (13521)(9.807)(764.0^{\pm 0.5}[\text{mm.Hg}])/1000 = 101306.7^{\pm 66.3} Pa$$

$$\rho_{air} = \frac{P_{atm}}{R.t_{room}} \quad (C.6)$$

$$\rho_{air} = \frac{101307^{\pm 66.3}}{287(273+23.5^{\pm 0.5})} = 1.191^{\pm 0.0021} Kg/m^3$$

Setting up the uncertainty function of Equation C.4, by taking its derivative and using Equation C.2 and considering the negligible uncertainty in voltmeter reading will lead to:

$$w_U = \frac{-0.5(2g)\frac{\rho_{Hg}}{\rho_{air}}\overline{volt}}{\sqrt{(2g\frac{\rho_{Hg}}{\rho_{air}}\overline{volt})^2}}w_{\rho_{air}} \quad (C.7)$$

Therefore, $w_U = 0.27 \text{ m/s}$, or $w_U = 0.9\%$

Reynolds Number

Primarily the random error for dynamic viscosity of air is calculated from a correlated equation applied in the data acquisition system:

$$\nu = 1.46 \times 10^{-6} \frac{T_{room}^{3/2}}{T_{room} + 110} \quad (C.8)$$

$$\text{Thus, } \nu = 1.46 \times 10^{-6} \frac{(23.5+273)^{3/2}}{23.5+273+110} = (1.834 \times 10^{-5})^{\pm 2.382 \times 10^{-6}}$$

The uncertainty of ν was calculated based on $t_{room} = 23.5^{\pm 0.5}C$ and via Equation C.2, which will in turn be used for the error analysis of Re_S :

$$Re_S = \frac{U_S}{\nu}$$

$$Re_S = \frac{(30.0)(0.0254)}{1.83 \times 10^{-3}} = 4.16 \times 10^4$$

Again by Equation C.2:

$$\begin{aligned} w_{Re_S} &= \left(\frac{.0254}{1.834 \times 10^{-5}} w_U \right)^2 + \left(\frac{30}{1.834 \times 10^{-5}} w_S \right)^2 + \left(-\frac{(30)(.0254)}{(1.834 \times 10^{-5})^2} w_v \right)^2 \\ &= 900.9, \text{ or } 0.2\% \end{aligned} \quad (C.9)$$

in which, from the former calculations, $w_U = .27$, $w_S = .0005$, and $w_v = 2.382 \times 10^{-8}$ has been used.

Heat Transfer Coefficient

$$\text{By } h_{max} = \frac{q}{t-T} = \frac{1080}{29.4-22.8} = 164. :$$

$$w_{h_{max}} = \left[\left(\frac{w_q}{29.4 - 22.8} \right)^2 + 2 \left(-\frac{1080 w_t}{29.4 - 22.8} \right)^2 \right]^{1/2} = 28.2, \text{ or } 17\% \quad (C.10)$$

To calculate the random error for each of the temperature and heat flux, the uncertainty values of .8 and 6.9 were plugged in the above mentioned equation. However, the error arising from the temperature is very significant.

Stanton Number

The maximum Stanton number was calculated by:

$$St_{max} = \frac{h_{max}}{\rho_{air} C_P U} = \frac{164.}{(1.19)(1006)(30.0)} = 4.57 \times 10^{-3}$$

And the error is analyzed by applying Equation C.2:

$$\begin{aligned} w_{St} &= \left[\left(\frac{w_h}{(1.19)(1006)(30.0)} \right)^2 + \left(-\frac{164. w_p}{(1.19)^2(1006)(30.0)} \right)^2 + \left(-\frac{164. w_U}{(1.19)(1006)(30.0)^2} \right)^2 \right]^{1/2} \\ &= 7.80 \times 10^{-4}, \text{ or } 17\% \end{aligned} \quad (C.11)$$

Nusselt Number

Similarly, the error analysis of equation $Nu_{S,max} = \frac{hS}{k_f}$ is followed:

$$w_{Nu_S} = \left[\left(\frac{S w_h}{k_f} \right)^2 + \left(\frac{h w_S}{k_f} \right)^2 \right]^{1/2} \quad (C.12)$$

Which will result in $w_{Nu_S} = \left[\left(\frac{(.0254)(28.2)}{.026} \right)^2 + \left(\frac{(164.)(.0005)}{.026} \right)^2 \right]^{1/2} = 27.7$, or 17.3%

Appendix D

Technical Keywords

Geometry of External Body after-body, fore-body, booster-base, blunt-base

Step Geometry backward-facing, rearward-facing, double, axisymmetric obstruction,

Heat Transfer convection, Axial conduction,

Extremely Severe Perturbation

Flow Zones separating, reattaching, redeveloping Boundary Layer, recirculating

Appendix E

Computer Programs

E.1 Measurement of Wall Temperature and Free Stream Velocity

Following is a program created for a "HP" model of data acquisition system to deliver the values of the air flow parameters by using measuring instruments.

```
! "HEXP1" FOR 2"; "HEXP2" FOR 1"; AND "HEXP3" FOR .5" CYLINDERS
! COMPONENTS OF SYSTEM ARE: Two Scanners 3495A with HP-IB=709, and 3455A with
!-IB=708, Voltmeter 3456A; HP-IB=722, Computer 9835A
! PROGRAM (HEXP) TO MEASURE AND TO COMPUTE HEAT-ELOW PARAMETERS
! RE-EDITED IN SUMMER 1992
PRINT "....."
PRINT "WALL TEMPERATURE MEASUREMENT PROGRAM WITH C/C THERMOCOUPLE"
PRINT
PRINT "STEP1. INPUT EXPERIMENTAL CONDITIONS"
PRINT "STEP2. FREE STREAM VELOCITY SETTING"
) PRINT "STEP3. HEATING START AND WAITING FOR STEADY STATE"
) PRINT "STEP4. INPUT HEAT FLUX DATA AND PRINT OUT WALL TEMP."
) PRINT "STEP5. HEAT TRANSFER COEFF. CALCULATION"
) PRINT "STEP6. PRINT OUT AND STORING THE RESULT."
) PRINT "....."
```

```

50 OPTION BASE 1
50 DIM Hx(40), Cp(40), Tc(40), Xp(40), Nux(40), Rex(40), Pr(40), Kx(40), Tf(40), Rox(
2)
70 Xp(1)=1.27
50 Xp(2)=2.54
30 Xp(3)=5.08
30 Xp(4)=6.35
10 Xp(5)=7.62
20 Xp(6)=8.89
30 Xp(7)=10.15
40 Xp(8)=11.43
50 Xp(9)=12.7
30 Xp(10)=13.97
70 Xp(11)=15.24
80 Xp(12)=16.51
90 Xp(13)=17.78
00 Xp(14)=20.32
10 Xp(15)=25.4
20 Xp(16)=30.48
30 Xp(17)=40.64
40 Xp(18)=50.8
50 Xp(19)=63.5
50 Xp(20)=76.2
70 Xp(21)=88.9
90 Xp(22)=101.6
90 Voltmeter=722
00 Scanner=709
10 Scan1=708
20 PRINT PAGE
30 BEEP
40 PRINT LIN(6)
50 PRINT "NOW, STEP1 BEGINS: PLEASE INPUT ROOM TEMP'C", ATM(MMHG)"
50 INPUT "ROOM TEMP =", Rtemp
70 BEEP
90 INPUT "ATMOSPHERIC PRESSURE(mmHG)", Atm_mmhg
90 BEEP
100 IF Rtemp<20 THEN 540
110 IF Rtemp>30 THEN 550
120 Rho_hg=13545-3.5*(Rtemp-20)
130 GOTO 570
140 Rho_hg=13570-2.4*(Rtemp-10)
150 GOTO 570
160 Rho_hg=13521
170 Patm=Rho_hg*9.80665*Atm_mmhg/1000
180 Rho_air=Patm/287/(273.15+Rtemp)
190 Visc0=1.46*(273.15+Rtemp)-1.5/(Rtemp+110+273.15)/1000000
200 BEEP
210 PRINT "NOW, STEP3 BEGINS: PLEASE CONNECT Px & Pr OE TRANSDUCER"
220 PRINT "THEN STRIKE ANY KEY AND PRESS CONTINUE"
230 INPUT AS
240 Call F=1
250 BEEP

```

```

40 PRINT "***** ZERO POINT READING *****"
50 INPUT "If you need Zero Adjustment, Press:Y, else any key",AS
60 IF AS="Y" THEN 760
70 GOTO 980
80 ! VOLTMETER 3455A
90 ! OUTPUT Voltmeter;"F1R7T3H1A1"
00 ! VOLTMETER 3456A
10 OUTPUT Voltmeter;"F1R1T1M0P0FL0"
20 ! 62000000000000 SHIFT FROM "HPT" TO "LPT" 0000 60 TO 1070, 1170 000000
30 ! OUTPUT Scanner;"29"
40 OUTPUT Scanner;"30"
50 Sum=0
60 FOR I=1 TO 10
70 TRIGGER Voltmeter
80 ENTER Voltmeter;R
90 Sum=Sum+R
00 NEXT I
10 Avg=Sum/10
20 PRINT " NOW, READING IS =";Avg;"Volt"
30 GOTO 950
40 INPUT "DO YOU WANT TO STOP ZERO ADJUST, PRESS; YES: Y NO: ANY KEY",AS
50 BEEP
60 IF AS="Y" THEN 980
70 GOTO 930
80 BEEP
90 BEEP
1000 ! PRINT "NOW, STEP3 BEGIN: PLEASE CONNECT PITOT TUBE LEADS TO P. TRANS."
1010 PRINT "IF YOU READY, TURN ON THE WIND TUNNEL AND WAIT UNTIL STEADY STATE"
1020 Sum=0
1030 ! OUTPUT Voltmeter;"F1R7T3H1A1"
1040 ! 00000000000000 SHIFT FROM "HPT" TO "LPT" 00000 60 TO 2320 & 3250 000000
1050 ! OUTPUT Scanner;"29"
1060 OUTPUT Scanner;"30"
1070 OUTPUT Voltmeter;"F1R1T1M0P0FL0"
1080 FOR I=1 TO 10
1090 TRIGGER Voltmeter
1100 ENTER Voltmeter;R
1110 Sum=Sum+R
1120 NEXT I
1130 Avg=Sum/10
1140 PRINT "NOW READING IS=";Avg;"Volt"
1150 ! Vel=SQR(2*9.80665*ABS(Avg)*Rho_hg/Rho_air)/100
1160 Vel=SQR(2*9.80665*ABS(Avg)*Rho_hg/Rho_air)/10
1170 Velf=Vel/Calf
1180 PRINT "Velocity measured by pressure transducer is=";Velf;"m/sec"
1190 GOTO 1020
1200 INPUT "IF YOU WANT TO STOP FLOW VELOCITY ADJUSTMENT TYPE 'Y'",AS
1210 IF AS="Y" THEN 1240
1220 GOTO 1020
1230 BEEP
1240 PRINT "NOW, YOU HAVE FINISHED TO GET REF. VELOCITY !"

```

```

1270 PRINT "NOW, STEP 4. BEGINS: PREPARING CONSTANT HEAT FLUX CONDITION"
1280 ! parameters of Curve Fitting
1290 ! Reference: 3-30 in catalog#3052A (9835A), SYS. LIBRARY, VOL IA
1300 ! Also: OMEGA Catalogue, Section T, Table 4
1310 C0=.10085091
1320 C1=25727.94369
1330 C2=-767345.8295
1340 C3=78025533.01
1350 C4=-9247486589
1360 C5=6.97688E11
1370 C6=-2.66192E13
1380 C7=3.94078E14
1390 INPUT "INPUT AMPER",Amper
1400 OUTPUT Scanner;"C"
1410 OUTPUT Scan1;"00"
1420 ! OUTPUT Voltmeter;"F4R7T3H1A1"
1430 OUTPUT Voltmeter;"F4R4T1M0P0FL0"
1440 Sum=0
1450 FOR I=1 TO 10
1460 TRIGGER Voltmeter
1470 ENTER Voltmeter;R
1480 Sum=Sum+R
1490 NEXT I
1500 Avg=Sum/10
1510 Tcj1=5041.6/(LOG(Avg)+7.15)-314.052
1520 PRINT "COLD JUNCTION TEMP. OF SCANNER 1 IS ";Tcj1
1530 OUTPUT Scan1;"C"
1540 OUTPUT Scanner;"20"
1550 Sum=0
1560 FOR I=1 TO 10
1570 TRIGGER Voltmeter
1580 ENTER Voltmeter;R
1590 Sum=Sum+R
1600 NEXT I
1610 Avg=Sum/10
1620 Tcj2=5041.6/(LOG(Avg)+7.15)-314.052
1630 PRINT "COLD JUNCTION TEMP. OF SCANNER 2 IS ";Tcj2
1640 OUTPUT Voltmeter;"F1R1T1M0P0FL0"
1650 OUTPUT Scanner;"32"
1660 Sum=0
1670 FOR I=1 TO 10
1680 TRIGGER Voltmeter
1690 ENTER Voltmeter;R
1700 Sum=Sum+R
1710 NEXT I
1720 Avg=Sum/10
1730 Vzbx=Avg+1E-6*((4.1277001E-2*Tcj2+3.8690238E1)*Tcj2)
1740 Tzbx=((((((C7*Vzbx+C6)*Vzbx+C5)*Vzbx+C4)*Vzbx+C3)*Vzbx+C2)*Vzbx+C1)*Vzbx+

```

```

750 PRINT "ZONE BCX TEMP. IS ";Tzbx
760 OUTPUT Scanner;"C"
770 Index=1
780 OUTPUT Scan1 USING "ZZ";Index
1750 OUTPUT Voltmeter;"F1R1T1M0P0FL0"
1200 Sum=0
1810 FOR I=1 TO 10
1820 TRIGGER Voltmeter
1830 ENTER Voltmeter;R
1840 Sum=Sum+R
1850 NEXT I
1850 Avg=Sum/10
1870 Vthj=Avg+1E-5*((4.1277001E-2*Tzbx+3.8680238E1)*Tzbx)
1880 Tw(Index)=((((((C7*Vthj+C6)*Vthj+C5)*Vthj+C4)*Vthj+C3)*Vthj+C2)*Vthj+C1)*
Vthj+C0
1890 Index=Index+1
1891 IF Index=3 THEN Index=4
1892 IF Index=11 THEN Index=12
1893 IF Index=13 THEN Index=14
1900 IF Index<16 THEN GOTO 1780
1910 OUTPUT Scan1;"C"
1920 Index=28
1930 OUTPUT Scanner USING "ZZ";Index
1940 Sum=0
1950 FOR I=1 TO 10
960 TRIGGER Voltmeter
970 ENTER Voltmeter;R
980 Sum=Sum+R
990 NEXT I
1000 Avg=Sum/10
1010 Vthj=Avg+1E-5*((4.1277001E-2*Tzbx+3.8680238E1)*Tzbx)
1020 Tw(Index-1)=((((((C7*Vthj+C6)*Vthj+C5)*Vthj+C4)*Vthj+C3)*Vthj+C2)*Vthj+C1
)*Vthj+C0
2030 Index=Index+1
2040 IF Index=17 THEN Index=28
2050 IF Index<30 THEN 1930
2060 OUTPUT Scanner;"C"
2070 PRINT "WALL-TEMP. SCANNING HAS FINISHED"
2080 PRINT "*****"
2090 PRINT
2100 PRINT "UPSTREAM REFERENCE TEMP. IS ";Tw(27)
2110 PRINT
2120 PRINT "WALL TEMP. DISTRIBUTION;"
2130 FOR I=1 TO 15
2140 PRINT "Tw(";I;)"=";Tw(I)
2150 NEXT I
2160 INPUT " IF YOU THINK Tw(I) ARE STEADY STATE, TYPE 'Y' ",YS
2170 IF YS<>"Y" THEN 1390
2180 OUTPUT Voltmeter;"F2R7T3H1A1"
2190 OUTPUT Voltmeter;"F2R1T4M0P0FL0"
2200 OUTPUT Scanner;"31"
2210 Sum=0

```

```

320 FOR I=1 TO 50
330 TRIGGER Voltmeter
340 ENTER Voltmeter;R
350 Sum=Sum+R
360 NEXT I
370 Vdf=Sum/50
380 PRINT "Vdf=",Vdf
390 PRINT "Tc1,Tc2, and Tbx are(C):",Tc1,Tc2,Tbx
400 OUTPUT Voltmeter;"F1R7T5H1A1"
410 ! @@@@@@@@@@@@@@ SHIFT FROM "HPT" TO "LPT" @@@@@@ GO TO 320 @@@@@@@@@@@@@@
420 ! OUTPUT Scanner;"29"
430 OUTPUT Scanner;"30"
440 Sum=0
450 FOR I=1 TO 10
460 TRIGGER Voltmeter
470 ENTER Voltmeter;R
480 Sum=Sum+R
490 NEXT I
500 Avg=Sum/10
510 ! Vel=SQR(2*9.80665*Avg*Rho_hg/Rho_air)/100
520 Vel=SQR(2*9.80665*Avg*Rho_hg/Rho_air)/10
530 Velf=Vel/Calf
540 PRINT "NOW STEP 5 BEGINS ; PRINT OUT EXPERIMENT CONDITIONS"
550 INPUT "Cylinder Diameter(mm)=" ,Dia
560 INPUT "Over-step Diameter(mm)=" ,Step_dia
570 INPUT "Cylinder Length(mm) Between First & last node =" ,Len
580 INPUT "INPUT DATE & TIME" ,Dates,BS
590 PRINT "DATE :",Dates," TIME :",BS
600 INPUT "INPUT EXP. FILE NAME" ,Cs
610 PRINT "EXP. FILE NAME IS =" ,Cs
620 PRINTER IS 7,6
630 PRINT LIN(1)
640 PRINT "*****"

650 PRINT "WALL TEMPERATURE DISTRIBUTION MEASUREMENT BY C/C THERMOCOUPLES "
660 PRINT "DATE : ";Dates,"TIME : ";BS
670 PRINT "EXP. FILE NAME IS = ";Cs
680 PRINT "*****"
690 PRINT "EXPERIMENTAL CONDITIONS:"
700 PRINT "-----"
710 PRINT "ROOM TEMPERATURE (°C) =" ,Rmtemp
720 PRINT "ATMOSPHERIC PRESSURE (mmHg) =" ,Atm_mmhg
730 FLOAT 4
740 PRINT "DYNAMIC VISCOSITY OF AIR (Kg/m.s) =" ,Visco
750 PRINT "DENSITY OF AIR (Kg/m^3) =" ,Rho_air
760 FIXED 2
770 PRINT "CYLINDER DIAMETER (mm) =" ,Dia
780 PRINT "STEP DIAMETER (mm) =" ,Step_dia
790 PRINT "Cylinder Length(mm) Between First & last node =" ,Len-12.7
800 PRINT "UPSTREAM VELOCITY (m/s) =" ,Velf
810 Red1=Velf*Rho_air*Dia/1000/Visco
820 PRINT
830 PRINT
840 FLOAT 2
850 PRINT "REYNOLDS NUMBER BASED ON DIA. = " ,Red1
860 PRINT "-----"

```

```

2790 PRINT "UPSTREAM TEMPERATURE (°C) =" ,Tw(27)
2800 PRINT "Zone Box TEMPERATURE (°C) =" ,Tzbx
2810 FIXED 2
2820 PRINT "SUPPLY CURRENT (A) =" ,Amper
2830 STANDARD
2840 PRINT "VOLTAGE DIFFERENCE(AC) ON TEST TUBE=" ,Udf
2850 Qtotal=Amper*Udf/(PI*Dia*(Len-12.7)*1E-5)
2860 FIXED 2
2870 PRINT "HEAT FLUX (W/M^2) =" ,Qtotal
2880 PRINT
2890 PRINT "WALL TEMPERATURE DISTRIBUTION : "
2900 PRINT " POSITION (inch)          TEMPERATURE "
2910 FIXED 2
2920 FOR I=1 TO 15
2930 PRINT " X(;"I;" )= ";Xp(I),Tw(I)
2940 NEXT I
2950 PRINT "-----"
"
2960 PRINT
2970 OUTPUT Scanner;"20"
2980 ! OUTPUT Voltmeter;"F4R7T3H1A1"
2990 OUTPUT Voltmeter;"F4R4T4M0P0FL0"
3000 Sum=0
3010 FOR I=1 TO 10
3020 TRIGGER Voltmeter
3030 ENTER Voltmeter;R
3040 Sum=Sum+R
3050 NEXT I
3060 Avg=Sum/10
3070 Tcj=5041.5/(LOG(Avg)+7.15)-314.052
3080 ! OUTPUT Voltmeter;"F1R7T3H1A1"
3090 OUTPUT Voltmeter;"F1R1T4M0P0FL0"
3100 OUTPUT Scanner;"32"
3110 Sum=0
3120 FOR I=1 TO 10
3130 TRIGGER Voltmeter
3140 ENTER Voltmeter;R
3150 Sum=Sum+R
3160 NEXT I
3170 Avg=Sum/10
3180 Vzbx=Avg+1E-6*((4.1277001E-2*Tcj+3.8680238E1)*Tcj)
3190 Tzbx=((((((C7*Vzbx+C6)*Vzbx+C5)*Vzbx+C4)*Vzbx+C3)*Vzbx+C2)*Vzbx+C1)*Vzbx+
C0
3200 OUTPUT Scanner;"28"
3210 Sum=0
3220 FOR I=1 TO 10
3230 TRIGGER Voltmeter
3240 ENTER Voltmeter;R
3250 Sum=Sum+R
3260 NEXT I
3270 Avg=Sum/10
3280 Vthj=Avg+1E-6*((4.1277001E-2*Tzbx+3.8680238E1)*Tzbx)
3290 Temp=((((((C7*Vthj+C6)*Vthj+C5)*Vthj+C4)*Vthj+C3)*Vthj+C2)*Vthj+C1)*Vthj+C
3300 PRINT "MEASURED FREE STREAM TEMPERATURE IS =" ;Temp
3310 Sum=0

```

```

320 ! @@@@@@@@@@@@@@ SHIFT FROM "HPT" TO "LPT" @@@@ END @@@@@@@@@@@@@@@@@@@@@@
330 ! OUTPUT Scanner:"29"
340 OUTPUT Scanner:"30"
350 OUTPUT Voltmeter:"FIRITIM0P0FLO"
360 FOR I=1 TO 10
370 TRIGGER Voltmeter
380 ENTER Voltmeter:R
390 Sum=Sum+R
400 NEXT I
410 Avg=Sum/10
420 ! Vel=SQR(2*9.80665*ABS(Avg)+Rho_hg/Rho_air)/100
430 Vel=SQR(2*9.80665*ABS(Avg)+Rho_hg/Rho_air)/100
440 Velf=Vel/Calf
450 PRINT "Velocity measured by pressure transducer is=";Velf;"m/sec"
460 PRINT
470 PRINT "-----"

3480 | END
3490 PRINT
3500 PRINTER IS 15
3510 Tw(15)=Velf
3520 Tw(16)=Temp
3530 Xp(13)=Amper
3540 Xp(14)=Qtotai
3550 Xp(15)=Vdf
3560 CREATE C$,5
3570 ASSIGN #3 TO C$
3580 FOR I=1 TO 16
3590 PRINT #3;Xp(I),Tw(I)
3600 NEXT I
3610 ASSIGN #5 TO C$
3620 FOR I=21 TO Index
3630 READ #5;Xp(I),Tw(I)
3640 PRINT Xp(I),Tw(I)
3650 NEXT I
3660 Index=0
3670 Sum=0
3680 PRINT "IF YOU WANT TO MEASURE CONTINUE, KEY Y"
3690 INPUT Y$
3700 IF Y$="Y" THEN 1020
3710 PRINT "CONGLATULATION ! YOU HAVE GOT MANY DATA. TURN OFF THE WIND TUNNEL
AND TAKE A REST."
3720 END

```

E.2 "TW FORTRAN", the Main Data Processor

The following program is set up in a way to process directly the output tables of results by the Latex word processor. The executing program is written for the Watfor77 compiler, run by CMS, in order to read the data files. A sample of data file is documented in Section E.3 . The program then creates the results in the format of input files for the Latex word processor. The latter files afterward were run by the "Tex Exec" file; the outputs are documented in Appendix A.

For each case-study in the present report, meanwhile, a similar program was written to produce the required pack of results for graphing purpose. The graphs were plotted, as are documented in APPENDIX B, using the Disspla graphic software.

```

-----C
C                               Created by Mossadeg S. NIAKI          C
C                               Final Edition: Feb.11, 1994          C
-----C

C from "interfaced" **TW* DATA*; makes "FORTRAN-LATEX" interfacial files
CHARACTER*73 LS2,LS3, LS4,LS5,LS6,LS7,LS8,LS9,LS10, L11,L12,
+           L14,L15,L16,L17,L18,L19, TX1, TX2, TX3, TX4, LE1, LE2, LE3,
+           LE5, LE8, LE9, LE10, LE11, LE12, LE13, LE14, D(20,30), HL
REAL KS, STMAX(18), NUMAX(18), NUDMAX(18), Q(18), U(18), MU(18), RO(18),
+ TINF(18), RES(18), RED(18), XMAX(18), HMAX(18), ERMAX(18), CNDMAX(18),
+ POS(20,30), T(20,30), DTX(20,30), ST(20,30), H(20,30), HX(20,30), KF,
+ STX(20,30), ER(20,30), NUS(20,30), NUD(20,30), COND(20,30), REX(20,30)
CC N:# OF NODE(.5":12; 1":25; 2":21); KS OF STEEL; KF OF AIR; M=16 VEL. CASE
PARAMETER (KS=16.3, KF=.026, E=2.7182818, M=16)
CC "S":STEP |(1A)1.27, (5A,1B,2")2.54, (1C)3.81, (5B)4.45, (1D)5.40|
CC "DO" & "DI": |0.5":1.27-1.09|; |1":2.54-2.06|; |2":5.08-4.47|,
PARAMETER(N=21, S=.0254, DO=.0508, DI=.0447, DD=DO+2.*S)
CC Read from #1; writes "PROPERTIES: #4", "NORMALIZED:#3", "CRITICAL: #7
OPEN(UNIT=1, FILE='2TW.DATA', STATUS='OLD')
C OPEN(UNIT=7, FILE='2TW.RESULT', STATUS='NEW')
C-- B=THICKNESS(METER)
B=(DO**2-DI**2)/(4.*DO)
DO 5 I=1,M
5 STMAX(I)=0
1 READ(1,1)LS2,LS3,LS4,LS5,LS6,LS7,LS8,LS9,LS10, L11,L12
1 FORMAT(11(/,1X,A72))
WRITE(4,2)LS2,LS3,LS4,LS5,LS6,LS7,LS8,LS9,LS10
2 FORMAT(8(1X,A72,/),1X,A72)
DO 100 I=1,M
READ(1,3)L14,L15,L16,L17,L18,L19

```

```

3  FORMAT(6(/,1X,A72))
   READ(1,4)U(I),Q(I),MU(I),RO(I)
4  FORMAT(4X,F4.1,11X,F7.2,17X,E8.3,/,7X,F4.2,/)
   RES(I)=RO(I)*U(I)*S/MU(I)
   RED(I)=RO(I)*U(I)*DO/MU(I)
   DO 10 J=1,N+1
10  READ(1,6)POS(I,J),T(I,J),D(I,J)
6  FORMAT(6X,F6.2,10X,F5.2,1X,A40)
   READ(1,7)LE1,LE2,LE3
7  FORMAT(2(1X,A70,/),1X,A70)
   WRITE(3,8)
8  FORMAT(/,1X,'X/S',3X,'X/D',3X,'X/DO',1X,'(X-XM)/XM',1X,'ST/STM',
+      1X,'NUS/NUM',1X,'NUD/NUM',1X,'CND/CNDM',3X,'REX')
   WRITE(3,9)U(I),U(I),U(I),U(I),U(I),U(I),U(I),U(I),U(I),U(I),U(I)
   WRITE(4,9)U(I),U(I),U(I),U(I),U(I),U(I),U(I),U(I),U(I),U(I),U(I)
9  FORMAT(' ',11('@',F4.1,1X),/,',',72('-'))
   WRITE(4,13)L14,L15,L16,L17,L18,L19, L11,L12
13  FORMAT(7(1X,A72,/),1X,A72)
   TINF(I)=T(I,1)
C-- Creates virtual end point for the finite difference purpose
   T(I,N+2)=T(I,N+1)
   POS(I,N+2)=POS(I,N+1)+POS(I,N+1)-POS(I,N)
   DO 15 J=2,N+1
15  DTX(I,J-1)=((2.*10000/(POS(I,J+1)-POS(I,J-1)))*((T(I,J+1)-
+      T(I,J))/(POS(I,J+1)-POS(I,J)))-((T(I,J)-T(I,J-1))/
+      (POS(I,J)-POS(I,J-1))))
   DO 30 J=2,N+1
   POS(I,J-1)=POS(I,J)
   D(I,J-1)=D(I,J)
30  T(I,J-1)=T(I,J)
   DO 20 J=1,N
   H(I,J)=ABS((Q(I)+B*KS*DTX(I,J))/(T(I,J)-TINF(I)))
   HX(I,J)=Q(I)/(T(I,J)-TINF(I))
   ST(I,J)= H(I,J)/(1006*U(I)*RO(I))
   STX(I,J)= Q(I)/(1006*U(I)*RO(I)*(T(I,J)-TINF(I)))
   NUS(I,J)=S*H(I,J)/KF
   NUD(I,J)= DO*H(I,J)/KF
   ER(I,J)=100.*ABS((H(I,J)-HX(I,J))/H(I,J))
   COND(I,J)=100.*ABS(B*KS*DTX(I,J)/Q(I))
   REX(I,J)=RO(I)*U(I)*POS(I,J)/MU(I)
   IF (J .GE. 3 .AND. ST(I,J) .GT. STMAX(I)) THEN
   STMAX(I)=ST(I,J)
   NUMAX(I)=NUS(I,J)
   NUDMAX(I)=NUD(I,J)
   XMAX(I)=POS(I,J)
   HMAX(I)=H(I,J)
   ERMAX(I)=ER(I,J)
   CNDMAX(I)=COND(I,J)
   ENDIF
20  CONTINUE
   WRITE(4,16)POS(I,1),T(I,1),D(1,J)
16  FORMAT(' 1', '&',F6.2, '&',F4.1,5('&'),A17)
   DO 25 J=2,N
   WRITE(4,11)J, POS(I,J), T(I,J), H(I,J), ST(I,J), NUS(I,J), NUD(I,J),
+      COND(I,J), D(I,J)
11  FORMAT(I2, '&',F6.2, '&',F4.1, '&',F4.0,3('&',E8.3), '&',F5.2,A17)
12  FORMAT(3(F5.2,1X),2X,F5.2,3X,F5.3,2(3X,F5.3),3X,F5.3,3X,E8.2)
25  WRITE(3,12)POS(I,J)/(S*100.), POS(I,J)/(100.*DD), POS(I,J)/(100.*DO),
+      (POS(I,J)-XMAX(I))/XMAX(I), ST(I,J)/STMAX(I), NUS(I,J)/NUMAX(I),
+      NUD(I,J)/NUDMAX(I), COND(I,J)/CNDMAX(I), REX(I,J)
   WRITE(3,14)RES(I),RED(I)
14  FORMAT(5X,'RES= ',E9.2,/,5X,'RED= ',E9.2)
   WRITE(4,7)LE1,LE2,LE3

```

100

CONTINUE

```

CALL REGS(RES,NUMAX,AS,BS,M)
CALL REGS(RED,NUDMAX,AD,BD,M)
CALL REGS(RED,STMAX,ASTS,BSTS,M)
CALL REGS(RES,STMAX,ASTD,BSTD,M)
C-- Reads end of data file literature, put them in "Critical nodes: #7"
  READ(1,401)LE5
401  FORMAT(/,1X,A72)
  READ(1,402)TX1, TX2, HL
402  FORMAT(1X,A42,1X,A8,1X,A9)
  READ(1,402)TX3, TX4, HL
  READ(1,403)LE8, LE9, LE10, LE11, LE12, LE13, LE14
403  FORMAT(6(1X,A72,/),1X,A72)
  WRITE(7,401)LE5
  WRITE(7,404)TX1, E**BS, TX2, AS
404  FORMAT(A42,1X, '(,E8.2, ' ', A8, E8.2, ' )$', '\\')
  WRITE(7,404)TX3, E**BD, TX4, AD
  WRITE(7,403)LE8, LE9, LE10, LE11, LE12, LE13, LE14
  DO 405 I=1,M
405  WRITE(7,406)U(I), XMAX(I), HMAX(I), RES(I), RED(I), STMAX(I), NUMAX(I),
+      NUDMAX(I), CNDMAX(I), HL
406  FORMAT(F4.1, '&', F5.2, '&', F4.0, 2('&', E7.2), 3('&', E8.3), '&', F4.1, 1X, A9)
  WRITE(7,7)LE1, LE2, LE3
  STOP
  END

```

|||||

Regression of NUMax(I) VS. Re(I)

|||||

```

SUBROUTINE REGS(RE,UNMAX,A,B,M)
REAL RE(M),UNMAX(M)
  SX=0
  SY=0
  SXS=0
  SYS=0
  SKY=0
  DO 410 I=1,M
    SX=SX+ALOG(RE(I))
    SY=SY+ALOG(UNMAX(I))
    SXS=SXS+(ALOG(RE(I)))**2
    SYS=SYS+(ALOG(UNMAX(I)))**2
410  SKY=SKY+(ALOG(RE(I)))*(ALOG(UNMAX(I)))
  A=(SX*SY-M*SKY)/(SX*SX-M*SXS)
  B=(SKY*SX-SY*SXS)/(SX*SX-M*SXS)
  XBAR=SX/(M*N)
  YBAR=SY/(M*N)
  DO 415 I=1,M
    DO 415 J=1,N
      SXBAR=SXBAR+(ALOG(RE(I,J))-XBAR)**2
415  SYBAR=SYBAR+(ALOG(UNMAX(I,J))-YBAR)**2
  SX=SQRT(SXBAR/((M*N)-1))
  SY=SQRT(SYBAR/((M*N)-1))
  DO 420 I=1,M
    DO 420 J=1,N
      ZX=(ALOG(RE(I,J))-XBAR)/SX
      ZY=(ALOG(UNMAX(I,J))-YBAR)/SY
420  SZXY=SZXY+ZX*ZY
  R=SZXY/((M*N)-1)
  RETURN
  END

```

