



**UNIVERSITI PUTRA MALAYSIA**

**DEVELOPMENT OF AN EXPERIMENTAL FACILITY FOR  
MEASUREMENT OF TANGENTIAL JET FLOW IN A SUDDEN  
EXPANSION CHANNEL**

**IRFAN BIN ABD RAHIM.**

**FK 2006 2**



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MEASUREMENT OF TANGENTIAL JET FLOW IN A SUDDEN  
EXPANSION CHANNEL**

**By**

**IRFAN BIN ABD RAHIM**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirements for the Degree of Master of Science**

**February 2006**



In the name of Allah, Most Gracious, Most Merciful

Lillahi Taala ....



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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**February 2006**

**Chairman: Abdul Aziz bin Jaafar, PhD**

**Faculty: Engineering**

This thesis describes the development of an experimental facility of a tangential jet flow in a sudden expansion channel. The present study is intended to clarify experimentally the relation between flow and geometrical variables on the thermal development using a point wise temperature measurements technique. The temperature measurements have been conducted on a flat plate inside a low speed open circuit wind tunnel. The mainstream flow has a maximum of temperature  $50^{\circ}\text{C}$ . The temperature was controlled by a 10 kVA/40 Ampere voltage regulator. A maximum velocity, ( $U_{\infty}$ ) at the mainstream intake is 10 m/s. The velocity on the coolant jet flow ( $U_j$ ) is between 2 m/s to 8 m/s, the expansion ratio (ER) is 1.2 and the Reynolds numbers, ( $Re_{\infty}$ ) is,  $1.3 \times 10^5$  on the mainstream location. The coolant distribution system is fabricated into three type of geometry: a slot shape  $20 \text{ mm}^2 / \text{mm}$ , a square shape 10 mm x 10 mm and a circular shape 10 mm of diameter. The surface temperature in the direction of the jet flow media is evaluated based on



the measured temperatures, obtained through the thermocouples over the flat surfaces. The jet flow is tangentially injecting a jet of cooling air at an exit angle of  $0^\circ$  from the coolant distribution system to the plate surface. The test plate is made of plastic material (acrylonitrile butadiene styrene) plate of 10 mm thick flat plate which is installed on the channel wall and instrumented with a stream wise row of T-type thermocouples. The thermocouples are spaced 25.4 mm apart along the center line of the plate. The temperature ratio between the cooling air temperature ( $T_i$ ) and the mainstream temperature ( $T_\infty$ ) is in the range of  $0.77 \leq \frac{T_i}{T_\infty} \leq 0.87$  while the velocity ratio between the cooling velocity ( $U_i$ ) and mainstream velocity ( $U_\infty$ ) is in range of  $0.2 \leq \frac{U_i}{U_\infty} \leq 0.7$ . From the observation made at the location  $X/h = 0.5$ , the cooling effectiveness ( $\eta$ ) for tangential jet flow emanating from the slot, square and circular holes geometry, is to be at maximum value of 0.8, 0.6, and 0.5 respectively. The data presented here would be off interest to engineers to gain further understanding in the development of heat transfer due to tangential jet flow in a sudden expansion channel.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

**PEMBANGUNAN SEBUAH KEMUDAHAN UJIKAJI UNTUK  
PENGUKURAN ALIRAN JET TANGEN DALAM ALUR  
PENGEMBANGAN MENDADAK**

Oleh

**IRFAN BIN ABD RAHIM**

**Februari 2006**

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Tesis ini menerangkan pembangunan peralatan ujikaji untuk aliran jet tangen dalam alur pengembangan mendadak. Kajian ini lebih tertumpu untuk menjelaskan perhubungan antara aliran dan pelbagai bentuk geometri terhadap pembangunan haba dengan menggunakan teknik pengukuran suhu secara titik. Pengukuran suhu telah dijalankan ke atas plat rata didalam terowong angin litar terbuka berhalaju rendah. Arus aliran tersebut mempunyai bacaan suhu maximum  $50^{\circ}\text{C}$  dengan suhu dikawal oleh pembolehubah voltan 10 kVA/40 Ampere. Halaju maksimum ( $U_{\infty}$ ) arus pada salur masuk adalah 10 m/s. Halaju pada aliran jet ( $U_j$ ) adalah diantara 2 m/s hingga 8 m/s. Nisbah pengembangan (ER) ialah 1.2 dan nombor Reynolds ( $Re_{\infty}$ ) bernilai  $1.3 \times 10^5$  pada lokasi arus. Sistem pengagihan pendinginan di fabrikasi kepada tiga jenis bentuk geometri: bentuk lubang alur  $20 \text{ mm}^2/\text{mm}$ , bentuk segiempat sama 10 mm x 10 mm dan bentuk bulat berdiameter 10 mm. Suhu permukaan dalam arah aliran jet adalah dinilai berdasarkan suhu pengukuran yang

diambil menerusi pengganding suhu menerusi permukaan plat rata. Aliran jet disuntik kepada permukaan plat secara tangen pada sudut keluar  $0^\circ$  dari sistem pengagihan pendinginan. Plat ujian dibuat daripada bahan plastik (acrylonitrile butadiene styrene) yang berukuran 10 mm tebal di mana plat ini dipasang pada saluran dinding dan dilengkapi dengan pengganding suhu jenis-T yang ditanam sepanjang plat rata tersebut. Setiap pengganding suhu dijarakan sebanyak 25.4 mm dibahagian tengah sepanjang plat tersebut. Nisbah suhu di antara suhu udara pendinginan ( $T_i$ ) dan suhu aliran utama ( $T_\infty$ ) adalah di dalam julat  $0.77 \leq \frac{T_i}{T_\infty} \leq 0.87$  manakala nisbah halaju di antara halaju pendinginan ( $U_i$ ) dan halaju aliran utama ( $U_\infty$ ) adalah didalam julat  $0.2 \leq \frac{U_i}{U_\infty} \leq 0.7$ . Melalui pemerhatian yang dibuat pada lokasi  $X/h = 0.5$  keberkesanan pendinginan ( $\eta$ ) bagi aliran jet tangen yang mengalir dari lubang yang bergeometri masing-masing: lubang alur, lubang-lubang bergeometri segiempat sama dan lubang-lubang bergeometri bulat adalah pada nilai maksimum 0.8, 0.6 dan 0.5. Data yang dibandingkan di sini akan menarik minat para jurutera untuk lebih memahami dalam pembangunan pemindahan haba berdasarkan aliran jet tangen dalam alur pengembangan mendadak.

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I certify that an Examination Committee met on 10<sup>th</sup> February 2006 to conduct the final examination of Irfan Bin Abd Rahim on his Master of Science thesis entitled “Development of an Experimental Facility for Measurement of Tangential Jet Flow in a Sudden Expansion Channel” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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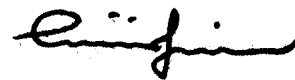
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## DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citations which have been duly acknowledged. I also declare that it has not been previously or currently submitted for any other degree at UPM or other institutions.

  
\_\_\_\_\_  
**IRFAN BIN ABD RAHIM**

Date: 24/03/2006

## TABLE OF CONTENTS

<b>DEDICATION</b>	<b>ii</b>
<b>ABSTRACT</b>	<b>iii</b>
<b>ABSTRAK</b>	<b>v</b>
<b>ACKNOWLEDGEMENTS</b>	<b>vii</b>
<b>APROVAL</b>	<b>viii</b>
<b>DECLARATION</b>	<b>x</b>
<b>LIST OF TABLES</b>	<b>xiv</b>
<b>LIST OF FIGURES</b>	<b>xv</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xx</b>

## CHAPTER

<b>1 INTRODUCTION</b>	<b>1</b>
1.1 Introduction	1
1.2 Problem Statement	6
1.3 Aims and Objective of the Study	7
1.4 Layout of Thesis	8
1.5 Contribution of Work	9
<b>2 LITERATURE REVIEW</b>	<b>10</b>
2.1 Introduction	10
2.2 Introduction to Film Cooling	10
2.2.1 Types of Film Cooling	11
2.3 Cooling Techniques in a Sudden Expansion Channel	14
2.3.1 Backward-Facing Step Flow	15
2.3.2 Normal Jet Flow	18
2.3.3 Tangential Jet Flow	25
2.4 Conclusion	31
<b>3 DESIGN CONSIDERATION</b>	<b>36</b>
3.1 Introduction	36
3.2 Dimensional analysis	36
3.3 Experimental Rig	45
3.4 Design and Fabrication of the Experimental Rig	48
3.4.1 Air Blower	48
3.4.2 Turbulence Reduction Screens	53
3.4.3 Primary Diffuser Duct (X2)	54
3.4.4 Settling Chamber (X3)	56
3.4.5 Primary Contraction Ducts (X4)	56
3.4.6 Heater Section	58
3.4.7 Working Section	62



3.5	Flow Measuring Equipment and Measurements	69
3.5.1	Pressure Acquisition System	69
3.5.2	Pressure Profile Measurement for Mainstream Intake	70
3.5.3	Air Speed at the Injection Hole	71
3.5.4	Mass Flow Rate Measurement	73
3.6	Thermal Field Measuring Instruments and Measurements	75
3.6.1	Temperature Measuring Equipments and Measurements	75
3.7	Derived Fluid, Flow and Thermodynamic Properties	78
3.7.1	Resultant velocity, $V$	79
3.7.2	Air density, $\rho$	79
3.7.3	Kinematics Viscosity, $\nu$	80
3.8	Conclusion	80
<b>4</b>	<b>METHODOLOGY</b>	<b>82</b>
4.1	Introduction	82
4.2	Flow Test Procedures	82
4.3	Thermal Test Procedures	86
4.4	Flow Measurements in the Experimental Rig	90
4.4.1	Boundary Layer Measurement and Profile	90
4.4.2	Pressure Distribution at the Inlet of Mainstream Channel	91
4.5	Conclusion	92
<b>5</b>	<b>RESULTS AND DISCUSSION</b>	<b>94</b>
5.1	Introduction	94
5.2	Reference Thermal Condition in the Working Section	94
5.2.1	Temperature of the Mainstream Flow, $T_{\infty}$	95
5.2.2	Temperature of the Tangential Jet Flow, $T_t$	96
5.2.3	Temperature Measurement on the Test Plate for Isothermal Flow	100
5.3	Thermal Analysis of the Tangential Jet Flow in a Sudden Expansion Channel	102
5.3.1	Slot Injection Hole (20mm x 230mm)	103
5.3.2	Square Injection Hole (10mm x 10mm)	112
5.3.3	Circular Injection Hole (10mm Diameter)	119
5.3.4	Parametric Study	129
5.4	Discussion of Experimental Result	136
5.5	Conclusion	137
<b>6</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	<b>141</b>
6.1	Introduction	141
6.2	Conclusion	141
6.2.1	Design and Development of the Experimental Facilities	142
6.2.2	Experiments on Cooling Effectiveness of the Tangential Jet Flow	143
6.3	Recommendation for Future Work	144



<b>REFERENCES</b>	<b>146</b>
<b>APPENDICES</b>	<b>151</b>
<b>BIODATA OF THE AUTHOR</b>	<b>225</b>



## LIST OF TABLES

<b>Table</b>		<b>Page</b>
2.1	Summary of previous research work on a film cooling technique in a sudden expansion channel	33
3.1	Table of the geometrical variables	37
3.2	Table of kinematics variables	37
3.3	Table of dynamic variables	38
3.4	Table of thermal variables	38
3.5	Components of the heat transfer facility	47
3.6	Geometrical properties of the injection hole insert	68
4.1	Instrument errors for measuring channels stations 1 to 19 on the test plate	89
4.2	Tabulated data of the boundary layer profile	91

## LIST OF FIGURES

Figure	Page
1.1 Schematics of a typical turbojet engine (reproduced from Rolls-Royce)	1
1.2 Turbojet cycle performances and for various turbine entry temperatures (reproduced from Cohen et al 1996)	3
1.3 Blade destruction due to high turbine entry temperature (reproduced from Rolls-Royce, 1973)	4
1.4 Combine internal and external cooling technique for a turbine blade (reproduced from Rolls Royce, 1973)	6
1.5 The phenomenology of secondary flow and applied on backward-facing step flow (Lukachko et al 2003)	7
2.1 Schematics of film cooling concept (Han and Ekkad, 1998)	13
2.2 Nature of flow filed with film cooling (Lakshminarayana, 1996)	14
2.3 Streamlines demonstrating flow features down stream from step (s=0.01m)	16
2.4 Streamlines on a y-plane close to the stepped wall (y/s=0.01), and on a Z-plane close to side wall (z/L=0.01): (a) s=0.008m; (b) S=0.01m; (c) s=0.012m. (Nie and Armaly 2001)	17
2.5 Showing on a y-plane close to the top flat wall (y/s=1.99) and on a z-plane close to the sidewall (z/L=0.01): (a) s=0.008m; (b) s=0.01m; (c) s=0.012m. (Nie and Armaly 2001)	17
2.6 The total temperature contours for the respective non-dimensional parameters specified with adiabatic wall thermal boundary Condition (reproduced from Milanés et al (2004))	23
2.7 The blowing ratio increase the local equivalence ratio within the recirculation zone becomes leaner (reproduced from (Milanés et al (2004))	24
2.8 Flow development of the tangential jet flow in sudden expansion channel for $Re_U = 6.3 \times 10^4$ and $0 \leq U_i/U_\infty \leq 1$ : (a) Streamline plot; (b) Velocity Profile (Jaafar et al 2005)	29
3.1 Schematics of the heat transfer facility	47
3.2 The centrifugal blowers	49





3.3	The primary air circuit	49
3.4	The secondary air circuit	50
3.5	A design boundaries for diffusers with screens (reproduced from Mehta, 1979)	55
3.6	Overall pressure drop coefficient requirements for a diffuser with screens (reproduced from Mehta, 1979)	56
3.7	Schematic of the winding heating elements meshes	59
3.8	Heater section	60
3.9	Schematics of electrical circuit for the heater section	61
3.10	Heater section assembly in the primary air circuit	62
3.11	Schematic installation of thermocouple	64
3.12	Installation of the thermocouple in streamwise direction	64
3.13	Temperature sensor for main channel wall	65
3.14	Assembly of instrumented flat plate	65
3.15	The test plate	66
3.16	Coolant distribution system	67
3.17	Injection hole inserts	67
3.18	Schematics of the slot shape insert	68
3.19	Schematics of the circular shape insert	68
3.20	Schematics of the square shape insert	69
3.21	The flow grid	71
3.22	A location of pitot tube at downstream holes	72
3.23	The step function	72
3.24	Schematic of a standard orifice plate (BS1042)	73
3.25	The customized orifice plate	74
3.26	Installation of static pressure ports at inlet and outlet of secondary contraction duct.	75

3.27	Temperature sensor for mainstream flow	76
3.28	An HP34910A multiplexer board	77
3.29	The Agilent (34970A) Data acquisition unit	78
3.30	The module slot built into the rear	78
4.1	A flow collector	83
4.2	Flow calibration equipment	84
4.3	Incorporating a digital manometer in the flow calibration equipment	84
4.4	Air pressure gauges (left – pre-setting air receiver pressure, right – the air pressure at the outlet)	85
4.5	A Digital Thermometer and Calibrator	86
4.6	Connecting the temperature calibrator to the temperature measuring instrument.	87
4.7	Instrument errors for each measuring channels stations 1 to 19 on the test plate	88
4.8	Boundary layer profiles in the test section	90
4.9	Pressure profile of mainstream intake ( $X=0\text{mm}$ )	92
5.1	Time history of $T_\infty$	95
5.2	Time history of $T_t$ ( $U_t = 0$ )	97
5.3	Time history of $T_t$ ( $U_t = 6 \text{ m/s}$ )	99
5.4	Surface temperature distribution on the flat plate for $U_\infty = 0$ and $U_t = 0$	101
5.5	Surface temperature distribution on the flat plate for $U_\infty > 0$ and $U_t > 0$	102
5.6	Surface temperature distributions for $Re_\infty = 1.0 \times 10^5$ , $U_t/U_\infty = 0.75$ and $20\text{mm}^2/\text{mm}$ slot injection hole	105
5.7	Cooling effectiveness distributions for $Re_\infty = 1.0 \times 10^5$ , $U_t/U_\infty = 0.75$ and $20\text{mm}^2/\text{mm}$ slot injection hole	105
5.8	Surface temperature distributions for $Re_\infty = 1.0 \times 10^5$ , $U_t/U_\infty = 0.5$ and $20\text{mm}^2/\text{mm}$ slot injection hole	107

5.9	Cooling effectiveness distributions for $Re_{\infty} = 1.0 \times 10^5$ , $U_t/U_{\infty} = 0.5$ and $20\text{mm}^2/\text{mm}$ slot injection hole	107
5.10	Surface temperature distributions for $Re_{\infty} = 1.0 \times 10^5$ , $U_t/U_{\infty} = 0.25$ and $20\text{mm}^2/\text{mm}$ slot injection hole	109
5.11	Cooling effectiveness distributions for $Re_{\infty} = 1.0 \times 10^5$ , $U_t/U_{\infty} = 0.25$ and $20\text{mm}^2/\text{mm}$ slot injection hole	109
5.12	Surface temperature distributions for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.6$ and $20\text{mm}^2/\text{mm}$ slot injection hole	111
5.13	Cooling effectiveness distributions for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.6$ and $20\text{mm}^2/\text{mm}$ slot injection hole	111
5.14	Surface temperature distribution for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.7$ and $10\text{ mm} \times 10\text{ mm}$ square injection hole	114
5.15	Cooling effectiveness distribution for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.7$ and $10\text{ mm} \times 10\text{ mm}$ square injection hole	114
5.16	Surface temperature distribution on the flat plate for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.5$ and $10\text{ mm} \times 10\text{ mm}$ square injection hole	116
5.17	Cooling effectiveness distribution for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.5$ and $10\text{ mm} \times 10\text{ mm}$ square injection hole	116
5.18	Surface temperature distribution on the flat plate for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.2$ and $10\text{ mm} \times 10\text{ mm}$ square injection hole	118
5.19	Cooling effectiveness distribution for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.2$ and $10\text{ mm} \times 10\text{ mm}$ square injection hole	118
5.20	Surface temperature distribution on the flat plate for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.7$ and $10\text{mm}$ diameter circular injection hole	121
5.21	Cooling effectiveness distribution for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.7$ and $10\text{mm}$ diameter circular injection hole	121
5.22	Surface temperature distribution for $Re_{\infty} = 1.3 \times 10^5$ $U_t/U_{\infty} = 0.5$ and $10\text{mm}$ diameter circular injection hole	123
5.23	Cooling effectiveness distribution for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.5$ and $10\text{mm}$ diameter circular injection hole	123
5.24	Surface temperature distribution for $Re_{\infty} = 1.3 \times 10^5$ $U_t/U_{\infty} = 0.4$ and $10\text{mm}$ diameter circular injection hole	125



5.25	Cooling effectiveness distribution for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.4$ and 10mm diameter circular injection hole	125
5.26	Surface temperature distributions for $Re_{\infty} = 1.3 \times 10^5$ , $U_t/U_{\infty} = 0.3$ and 10m diameter circular injection hole	128
5.27	Cooling effectiveness distributions for $Re_{\infty} = 1.0 \times 10^5$ , $U_t/U_{\infty} = 0.3$ and 10mm diameter circular injection hole	128
5.28	Effects of $T_{\infty}/T_t$ , $Re_{\infty}$ and $U_t/U_{\infty}$ on surface temperatures for 20mm <sup>2</sup> /mm slot injection hole	131
5.29	Effects of $T_{\infty}/T_t$ , $Re_{\infty}$ and $U_t/U_{\infty}$ on cooling effectiveness for 20mm <sup>2</sup> /mm slot injection hole	131
5.30	Effects of $U_t/U_{\infty}$ on surface temperatures for $Re_{\infty} = 1.3 \times 10^5$ , $T_{\infty}/T_t = 1.16$ and 10mm x 10mm square injection hole	133
5.31	Effects of $U_t/U_{\infty}$ on cooling effectiveness for $Re_{\infty} = 1.3 \times 10^5$ , $T_{\infty}/T_t = 1.16$ and 10mm x 10mm square injection hole	133
5.32	Effects of $U_t/U_{\infty}$ on cooling effectiveness for $Re_{\infty} = 1.3 \times 10^5$ , $T_{\infty}/T_t = 1.16$ and 10mm diameter circular injection hole	135
5.33	Effects of $U_t/U_{\infty}$ on cooling effectiveness for $Re_{\infty} = 1.3 \times 10^5$ , $T_{\infty}/T_t = 1.16$ and 10mm diameter circular injection hole	135

## LIST OF ABBREVIATIONS

<i>a</i>	geometrical shape (mm)
$a_o$	speed of sound (m/s)
$A_{out}$	area of outlet (m <sup>2</sup> )
$A_t$	cross sectional area (m <sup>2</sup> )
$A$	area (m <sup>2</sup> )
$A$	Agilent 34970A Temperature data logger
$A$	area ratio
<i>b</i>	geometrical shape (mm)
$B1, B2$	pressure scanning module
$B$	Blowing ratio $\left( \frac{\rho_t U_t}{\rho_\infty U_\infty} \right)$
<i>c</i>	geometrical shape (mm)
$c_p$	specific heat of constant pressure
$c_v$	specific heat of constant volume
$C_p$	pressure coefficient
$C_f$	skin-friction coefficient
$C$	computer
$C$	contraction ratio
<i>d</i>	hydraulic diameter (m)
<i>d</i>	orifice diameter (mm)
<i>d</i>	geometrical shape (mm)

$dz$	width of the cooled test plate (m)
$D_a$	Damkohler number $\left( \frac{\tau_{flow}}{\tau_{chem}} \right)$
$D_t$	hydraulic diameter (m)
$D$	diameter of downstream and upstream pipe (mm)
DA	primary voltage regulator
DB	secondary voltage regulator
DC	Ammeter
$e$	thickness of the orifice (mm)
$E_{in}$	energy in (W)
$E_{out}$	energy out (W)
$E_{system}$	total energy (W)
$E$	thickness of the orifice plate (mm)
ER	expansion ratio
$f$	function
$F$	thrust produced ( $Ns/kg$ )
$F$	angle of bevel orifice plate
$G$	orifice upstream edge
$h$	step height (mm)
$h$	convection heat transfer coefficient ( $W/m^2K$ )
$h_0$	local convection heat transfer coefficient ( $W/m^2K$ )
$H$	channel high (mm)

$H$	enthalpy (kJ)
$H$	shaft power input
$H$	high (m)
$H$	orifice downstream edge
$H^*$	heat release potential, $\left( \frac{T_{ad} - T_{t,\infty}}{T_{t,\infty}} \right)$
$H$	heat transfer coefficient ( $\text{W.m}^{-2}.\text{K}^{-1}$ )
$I$	current (A)
$I$	specific momentum ratio $\left( \rho_t U_t^2 / \rho_\infty U_\infty^2 \right)$
$I$	orifice downstream edge
$k$	thermal conductivity ( $\text{W.m}^{-1}.\text{K}^{-1}$ )
$K_{screen}$	<i>screen</i> pressure drop coefficients
$K$	<i>screen</i> pressure drop coefficients
$K_{sum}$	overall pressure drop coefficients
KE	kinetic energy
$L_s$	length of working section channel lip respectively (m)
$L$	length of working section (m)
$L$	dimensionless (m)
$\dot{m}$	mass flow rate ( $\text{kg.s}^{-1}$ )
$M$	dimensionless (kg)
$M_0$	inlet mach number
$M_\infty$	mainstream mach number

$M_a$	mach number
$n$	number of holes
Nu	Nusselt number, $Nu = \frac{hL}{k}$
$P_t$	total pressure (Pa)
$P_s$	static pressure (Pa)
P	absolute pressure (Pa or Psi)
P	power (Watt)
Pa1	Pitot-Static tube
Pb1,2,3	static pressure taping (secondary settling chamber)
Pb4,5	static pressure taping (orifice plate)
$Pr_x$	Prandtl number, $Pr = \frac{c\mu}{k}$
PE	potential energy
$q$	dynamic pressure ( $P_t - P_s$ )
$q''$	heat flux ( W/m <sup>2</sup> )
$q_0''$	local heat flux ( W/m <sup>2</sup> )
$Q_{in}$	heat transfer of the energy into the system
$Q_{out}$	heat transfer of the energy out the system
$R$	electrical resistance ( $\Omega$ )
$R_{1,2,3,4,5}$	electrical resistance ( $\Omega$ )
$R_{T1,T2}$	total electrical resistance ( $\Omega$ )



R	gas constant for air (J/kg.K)
Re	Reynolds number, $Re = \frac{\rho u d}{\mu}$
Re <sub>d</sub>	Reynolds number based on hole diameter, $Re = \frac{U_{\infty} d}{\nu_{\infty}}$
Re <sub>s</sub>	Reynolds number based on slot, $Re = \frac{U_{\infty} d}{\nu_{\infty}}$
Re <sub>u</sub>	Reynolds number based on mainstream velocity, $Re = \frac{U_{\infty} (H - h)}{\nu_{\infty}}$
Ri	Bouyancy parameter,
RS	RS Component
s	step
S	duct local parameter
S	separation between the injection hole
St <sub>x</sub>	Stanton number, $\left( \frac{Nu_L}{Re_L Pr} = \frac{h}{\rho V c_p} \right)$
T <sub>∞</sub>	mainstream flow temperature (°C)
T <sub>0</sub>	starting temperature reading (°C)
T <sub>a,b,c,d</sub>	thermocouple probe (T-type)
T <sub>f</sub>	film temperature (°C)
T <sub>s</sub>	surface temperature (°C)
T <sub>i</sub>	cooling flow temperature (°C)
T <sub>w</sub>	wall temperature (°C)
T	absolute temperature (°C or °K)