UNIVERSITI PUTRA MALAYSIA

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

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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

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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

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

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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 $50°C$. The temperature was controlled by a 10 kVA/40 Ampere voltage regulator. A maximum velocity, (U_∞) at the mainstream intake is 10 m/s. The velocity on the coolant jet flow (U_t) is between 2 m/s to 8 m/s, the expansion ratio (ER) is 1.2 and the Reynolds numbers, (Re_∞) is, 1.3×10^5 on the mainstream location. The coolant distribution system is fabricated into three type of geometry: a slot shape 20 mm^2/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° from the coolant distribution system to the plate surface. The test plate is made of plastic material (acrylonitrile butadiene stryrene) 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_t) and the mainstream temperature (T_∞) is in the range of $0.77 \leq \frac{T_t}{T_\infty} \leq 0.87$ while the velocity ratio between the cooling velocity (U_t) and mainstream velocity (U_∞) is in range of $0.2 \leq \frac{U_t}{U_\infty} \leq 0.7$. From the observation made at the location $X/h = 0.5$, the cooling effectiveness (η) 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

Febuari 2006

Pengerusi: **Abdul Aziz Bin Jaafar, PhD**

Fakulti: **Kejuruteraan**

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 $50°$ C dengan suhu dikawal oleh pembolehubah voltan 10 kVA/40 Ampere. Halaju maksimum (U_∞) arus pada salur masuk adalah 10 m/s. Halaju pada aliran jet (U_t) adalah diantara 2 m/s hingga 8 m/s. Nisbah pengembangan (ER) ialah 1.2 dan nombor Reynolds (Re_∞) bernilai 1.3×10^5 pada lokasi arus. Sistem pengagihan pendiginan di fabrikasi kepada tiga jenis bentuk geometri: bentuk lubang alur 20 mm^2/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° dari sistem pengagihan pendinginan. Plat ujian dibuat daripada bahan plastik (acrylonitrile butadiene stryrene) 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_t) dan suhu aliran utama (T_∞) adalah di dalam julat $0.77 \le \frac{T_t}{T_\infty} \le 0.87$ manakala nisbah halaju di antara halaju pendinginan (U_t) dan halaju aliran utama (U_∞) adalah didalam julat $0.2 \le \frac{U_t}{U_\infty} \le 0.7$. Melalui pemerhatian yang dibuat pada lokasi $X/h = 0.5$ keberkesanan pendinginan (η) 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 10th 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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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

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a	geometrical shape (mm)
a_o	speed of sound (m/s)
A_{out}	area of outlet (m^2)
A_t	cross sectional area (m^2)
A	area (m^2)
A	Agilent 34970A Temperature data logger
A	area ratio
b	geometrical shape (mm)
$B1, B2$	pressure scanning module
B	Blowing ratio $\left(\frac{\rho_t U_t}{\rho_\infty U_\infty}\right)$
c	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
d	hydraulic diameter (m)
d	orifice diameter (mm)
d	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 (W.m^{-2}.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 (W.m^{-1}.K^{-1})
K_{screen}	*screen* pressure drop coefficients
K	*screen* 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 (kg.s^{-1})
M	dimensionless (kg)
M_0	inlet mach number
M_∞	mainstream mach number

M_a	mach number
n	number of holes
Nu	Nusselt number, $\mathrm{Nu} = \frac{hL}{k}$
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, $\mathrm{Pr} = \frac{c\mu}{k}$
PE	potential energy
q	dynamic pressure $(P_t - P_s)$
q''	heat flux (W/m^2)
q_0''	local heat flux (W/m^2)
Q_{in}	heat transfer of the energy into the system
Q_{out}	heat transfer of the energy out the system
R	electrical resistance (Ω)
$R_{1,2,3,4,5}$	electrical resistance (Ω)
$R_{T1,T2}$	total electrical resistance (Ω)

R	gas constant for air (J/kg.K)
Re	Reynolds number, $\mathrm{Re} = \dfrac{\rho u d}{\mu}$
Re_d	Reynolds number based on hole diameter, $\mathrm{Re} = \dfrac{U_\infty d}{v_\infty}$
Re_s	Reynolds number based on slot, $\mathrm{Re} = \dfrac{U_\infty d}{v_\infty}$
Re_u	Reynolds number based on mainstream velocity, $\mathrm{Re} = \dfrac{U_\infty (H-h)}{v_\infty}$
Ri	Bouyancy parameter,
RS	RS Component
s	step
S	duct local parameter
S	separation between the injection hole
St_x	Stanton number, $\left(\dfrac{Nu_L}{\mathrm{Re}_L \mathrm{Pr}} = \dfrac{h}{\rho V c_p}\right)$
T_∞	mainstream flow temperature (°C)
T_0	starting temperature reading (°C)
$T_{a,b,c,d}$	thermocouple probe (T-type)
T_f	film temperature (°C)
T_s	surface temperature (°C)
T_t	cooling flow temperature (°C)
T_W	wall temperature (°C)
T	absolute temperature (°C or °K)