DRAG REDUCTION IN DUCTS USING STRUCTURED INTERNAL SURFACES

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in chemical engineering.

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STUDENT'S DECLARATION

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

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FEBRUARY 2017

DEDICATION

To

My Dear Mother and Father

In Recognition of Their Worth, Love, and Respect

This Thesis Dedicated to the Memory of My Best Friend,

Dr. Hayder Al-Safar

May He Rest in Peace

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Hassan Dhiaaldeen Mahammed. Al-Hashem

ABSTRAK

Menambahbaikkan aliran permukaan tenggelam seperti di dalam saluran paip, kapal selam, dan kapal terbang telah menarik minat ramai penyelidik sejak beberapa dekad yang lalu. Banyak tenaga yang telah digunakan untuk menangani daya seretan yang kebanyakannya mengakibatkan kehilangan tenaga. Beberapa teknik telah dijalankan untuk mencari jalan yang sesuai bagi menambahbaik aliran bagi permukaan tenggelam Terkini, kaedah yang paling popular untuk mengurangkan seretan ialah penggunaan aditif kaedah aktif. Walaubagaimanapun, kesemua kaedah aktif ini ada keburukannya seperti degradasi mekanikal, perubahan sifat kimia dan fizikal cecair serta menjadi toksik dan sebahagiannya tidak boleh terurai secara semulajadi dan banyak peringkat tambahan yang perlu dilakukan untuk memastikan aditif itu sesuai. Ini menyebabkan penambahan kos seiring dengan aditif tersebut. Hal ini telah membawa kepada penyelidikan baru yang lebih mesra alam dan pengurangan daya seretan yang tidak melibatkan aditif. Dalam kajian terbaru, dua set riblet direkabentuk dan dipalsukan. Set-set tersebut diklasifikasikan berdasarkan alur mengikut orientasi (membujur dan melintang). Riblet kedua-dua set mengandungi lima subset dari lima bentuk riblet (segi tiga, trapezoid, segi tiga djarakkan, alur-L, dan alur-I). Setiap bentuk riblet mempunyai ketinggian 600, 800, dan 1000 μm dengan jarak yang berlainan supaya daya paduan ke arah aliran kekal sama. Hal ini bagi menyediakan perbandingan yang tepat pada kesan riblet ke arah aliran bergelora di dalam sistem aliran tertutup dengan keadaan operasi yang berbeza. Pengagihan halaju ke atas permukaan yang dikaji ditentukan menggunakan system mini-LDV. Data eksperimen menunjukkan peratusan pengurangan seretan (%DR) adalah lebih tinggi dan lebih efisyen apabila arah aliran permukaan berstruktur ialah membujur. Menambahkan ketinggian riblet akan menyebabkan penurunan %DR. Keputusan ujikaji menunjukkan riblet alur-U mempunyai %DR yang tertinggi dengan penambahbaikan aliran maksimum sebanyak 13.7% dilihat pada reka bentuk 600 x 750 μm. Ukuran penurunan daya tekanan pada kerja ini memberikan indikasi yang jelas serta pemetaan sifat aliran ke atas permukaan yang dikaji, dimana pengurangan dalam bacaan daya tekanan dikesan dengan tempoh masa yang hampir konsisten. Ini merupakan indikasi yang jelas tentang ciptaan dan pemecahan struktur bergelora ke atas permukaan apabila struktur permukaan itu berubah. Pengagihan halaju mini-LDV mendedahkan fakta bahawa sifat aliran ke atas permukaan rib berubah sepenuhnya apabila dibandingkan dengan permukaan licin. Nilai halaju permukaan rib adalah lebih rendah daripada permukaan licin apabila ukuran laser ialah 1 mm daripada arah permukaan dan ianya menjadi lebih tinggi berbanding nilai permukaan licin apabila ia mencapai titik ukuran maksimum (25 mm di atas permukaan). Dapatan yang sebegitu menyokong idea untuk mengubah arah gelora itu ke arah tengah salur di mana tahap pergolakan menjadi lebih tinggi. Kesimpulannya, didapati bahawa dimensi geometri boleh mengawal kesan pengurangan daya seretan walaupun arah aliran tersebut melintang dimana sebahagian kesan pengurangan daya seretan dilihat.

ABSTRACT

Enhancing the flow of submerged surfaces as in pipeline, submarines, ships, and even airplanes attracted enormous numbers of researchers in the past few decades. A huge amount of energy has spent to overcome the drag force which results in a loss in energy. Several techniques were conducted to find the possible way to enhance the flow of submerged surfaces. Currently the most popular method for reducing drag employed the use of additives (active means). However, these active means do have drawbacks such as mechanical degradation, altering the chemical and physical properties of the fluid they inhabit as well as being toxic and non-biodegradable for the most part and many extra stages must be included to ensure that an additive is suitable. As a result, the additive increases costs and reverses savings. This has spurred new research aimed to explore more nature-friendly, non-additive means of drag reduction. In the present study, two sets of riblets we designed and fabricated, the sets classified according to groove according to orientations (longitudinal and transverse) riblets both sets contain five subsets of five riblet shapes (triangular, trapezoidal, spaced triangular, L-groove, and U-groove). Each riblet shape had heights of 600, 800 and 1000 μm, with varied spacing so that the resultant protrusions into the flow remained similar to provide an accurate comparison of the effects of riblets on turbulent flow in a closed loop channel flow system with different operating conditions. The velocity distribution over the investigated surfaces was determined using mini-LDV system. The experimental data showed that the percentage drag reduction (%DR) was higher and more efficient when the direction of flow over the structured surfaces is longitudinal. Increasing the riblets height led to a decrease in the %DR reported. The experimental results showed that the U-groove riblets had the highest %DR values with maximum flow enhancement of 13.7% observed in 600 ×750 μm design. The pressure drop measurements of the present work gave a clear indication and mapping of the flow behavior over the investigated surfaces, where reductions in the pressure drop readings are spotted with almost consistent time periods and that is a clear indication of the creation and bursting of turbulence structures over the surfaces when the structure of the surface is changed. The mini-LDV velocity distribution reveals the fact that the flow behavior over the rib surfaces changes completely when compared to the smooth surface. The velocity values of the rib surfaces were lower than that of the smooth surfaces when the laser measurements were 1 mm from the surface, and it became much higher than the values of the smooth surfaces when it reaches its maximum measurement point (25 mm above the surface). Such finding supports the idea of redirecting the turbulence towards the center of the duct where the degree of turbulence became higher. Finally as a conclusion, it was found that the geometry dimensions can massively control the drag reduction effect even if the direction of flow is transverse where certain drag reduction effects can be measured.

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LIST OF SYMBOLS

A	Area (mm^2)
c_f	Skin friction coefficient
τ_w	Wall shear stress $(^N/_{m^2})$
D_h	Channel hydraulic diameter (mm)
P	Wetted perimeter of the duct
L	length of the test section (m)
P	Pressure (Pa)
ΔP_{Smooth}	Pressure drop over smooth surface (Pa)
ΔP_{riblet}	Pressure drop over rib surface (Pa)
Re	Reynolds Number
u	Mean velocity (m/sec)
v	Kinematic viscosity $(^{m^2}/_{sec})$
ρ	Density $(^{Kg}/_{m^2})$
h	Riblet height (µm)
s	Peak-to-peak riblet spacing (µm)
τ	Groove tip (µm)
ω	Groove base (µm)
h^+	Non-dimensional groove height
s^+	Non-dimensional groove space
Ɛ	Turbulent energy dissipation rate per unit mass (m^2/s^3)

LIST OF ABBREVIATIONS

DRA	Drag Reducing Agents
OLDs	Outer Layer Devices
BLADEs	Boundary Layer Devices
LEBUs	Large Eddy Breakup Devices
TAPPMs	Tandem Arrayed Parallel Plate Manipulator
WEDM	Wire Electrical discharge Machining
CNC	Computer Numerical Controlled Milling Machine
LDV	Laser Doppler Velocimetry
LIF	Laser Induced Florescence

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