UNIVERSITI PUTRA MALAYSIA

EFFECTS OF HYDROGEN ENRICHMENT ON COMPRESSED NATURAL GAS ENGINE PERFORMANCE AND EMISSIONS

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By

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

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Faculty : Engineering

A quasi-dimensional thermodynamic cycle simulation with a two-zone combustion model is developed to simulate the combustion characteristics, performance and emissions of a four-cylinder spark ignition (SI) engine fueled with CNG-hydrogen blends. This model, applying the first law of thermodynamics for a closed system, is inclusive of the flame front propagation computed through geometric modeling and turbulent entrainment modeling to predict the mass fraction burned during the combustion process which is an important performance parameter for engine cycles. The hypothesis is enrichment of H_2 to CNG fuel can increase burning velocity and wide-range equivalence ratio, resulting in decreasing sparks advanced and stabilize flame propagation during combustion process. The CNG-H_2 mixtures were prepared with varied hydrogen fractions from 0-40% with the increment of 10%. The engine was operated over a wide range of equivalence ratios of 0.55 to 1.2, at a constant engine speed of 3000 rpm and the intake pressure of 86,525 kPa. In addition, the

spark timing for each of the tests was adjusted to achieve maximum brake torque. Simulations with Matlab were performed under different engine operating conditions. This model was successfully developed to predict characteristic combustion, engine performance and emissions, where, a good agreement was found between the experimental data and simulation results. By the addition of H_2 of up to 40%, a decrease in the fuel burning duration was observed leading to a reduction of 1.5% heat loss at stoichiometric mixture. In addition, the fuel mixtures make it possible to run the engine under lean equivalence ratios due to improve the combustion stability at extremely lean conditions, so it will be improving engine brake power by increasing the hydrogen fraction. An increase in brake power of about 2.14% at 0.55 equivalence ratio was obtained, accompanied by a reduction in fuel consumption of about 9.5% at the same equivalence ratio and decreases the brake specific fuel consumption about 8.8% and 11.4% at stoichiometric and 0.55 equivalence ratio, respectively. The increase in H_2 fraction also contributes to the decreasing of CO_2 and CO emissions where a decrease of 14.98-15.48% and 28.87%-7.66% of CO_2 and CO emissions were observed, respectively, for lean to stoichiometric mixtures. However, an increase in NO emissions of about 3.54% was observed at 10% H_2. Maximum NO emissions were obtained at 0.9 equivalence ratio for all fuel mixtures including CNG fuel while lower NO emissions were obtained at leaner mixtures under 0.7 of equivalence ratio. The hypothesis for this study is accepted.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PENGARUH PENGAYAAN HIDROGEN TERHADAP PRESTASI ENJIN GAS ASLI TERMAMPAT DAN EMISI

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Simulasi kitaran termodinamik kuasi-dimensi dengan model pembakaran dwi-zon telah dibangunkan bagi menjalankan simulasi sifat pembakaran, prestasi dan emisi enjin percikan api empat-silinder menggunakan campuran bahan api CNG-hidrogen. Model-model ini mengaplikasikan hukum pertama termodinamik bagi kitaran tertutup dan turut mengambil kira pemodelan geometrik propagasi nyala ke hadapan dan pemodelan pengiringan bergelora bagi meramalkan pecahan jisim yang terbakar ketika proses pembakaran yang mana pecahan jisim tersebut merupakan parameter yang penting dalam menentukan prestasi kitaran enjin. Hipotesis adalah pengkayaan H_2 dalam bahan api CNG boleh meningkatkan kelajuan pembakaran dan julat lebar nisbah setara, yang menghasilkan penurunan mara bunga api dan penstabilan kemaraan nyala semasa proses pembakaran. Campuran CNG-H_2 mempunyai pecahan H_2 bertingkat dari 0-40% dengan peningkatan sebanyak 10%. Enjin telah dijalankan di bawah nisbah kesetaraan daripada 0.55 hingga 1.2, pada kelajuan enjin tetap 3000 rpm dan tekanan

masukan 86,525 kPa. Tambahan lagi, pemasaan percikan api bagi setiap ujian telah disesuaikan bagi mendapatkan daya kilas brek maksimum. Simulasi dengan perisian Matlab telah dijalankan untuk pelbagai keadaan operasi. Model telah dibangunkan dengan jayanya untuk meramalkan ciri pembakaran, prestasi enjin serta keluaran, yang mana persamaan yang hamper bagi keputusan eksperimen dan simulasi. Dengan penambahan H_2 ke tahap 40%, pengurangan pada tempoh pembakaran bahan api telah dilihat yang melangkah kepada pengurangan kehilangan haba sebanyak 1.5% pada campuran stoikiometri. Tambahan lagi, campuran bahan api membolehkan enjin beroperasi pada keadaan nisbah setara kurang demi meningkatkan penstabilan pembakaran pada keadaan kurang lampau supaya kuasa brek enjin ditingkatkan dengan peningkatan pecahan hydrogen. Peningkatan kuasa brek sebanyak 2.14% pada nisbah kesetaraan 0.55 telah dilihat diiringi dengan pengurangan penggunaan bahan api sebanyak 9.5% pada nisbah kesetaraan yang sama dan pengurangan penggunaan bahan api tentu brek sebanyak 8.8% dan 11.4% pada nisbah stoichiometrik serta 0.55 pada nisbah setara. Penambahan pecahan H_2 juga menyumbang kepada pengurangan emisi CO_2 dan CO di mana pengurangan masing-masing adalah 14.98%-15.48% dan 28.87%-7.66% pada campuran lemah hingga stoikiometri. Walaubagaimanapun, peningkatan pada emisi NO sebanyak lebih kurang 3.54% telah dilihat pada pecahan 10% H_2. Emisi NO maksimum telah diperolehi pada nisbah kesetaraan 0.9 bagi kesemua campuran bahan api termasuk pada 0% H_2 dan emisi NO yang lebih rendah diperolehi pada campuran lebih lemah di bawah nisbah kesetaraan 0.7. Oleh yang demikian, hipotesis diterima.

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Asnawi, August 2011

I certify that a Thesis Examination Committee has met on 16 August 2011 to conduct the final examination of Asnawi on his thesis entitled "Effects of Hydrogen Enrichment on Compressed Natural Gas Engine Performance and Emissions" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The committee recommends that the student be awarded the Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

A S N A W I

Date: 16 August 2011

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