



Faculty of Mechanical Engineering

A NOVEL HYBRID DESIGN OF HHO GENERATOR CELL FOR
IMPROVED ENGINE PERFORMANCE AND EMISSION

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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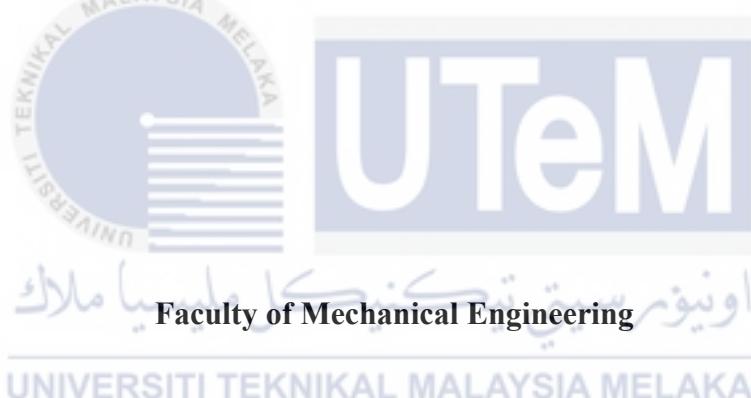
Doctor of Philosophy

2022

**A NOVEL HYBRID DESIGN OF HHO GENERATOR CELL FOR IMPROVED
ENGINE PERFORMANCE AND EMISSION**

AJAT SUDRAJAT

**A thesis submitted
in fulfillment of the requirements for the degree of Doctor of Philosophy**



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this thesis entitled “A Novel Hybrid Design of HHO Generator Cell for Improved Engine Performance and Emission” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 4 December 2020



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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.



Signature :

Supervisor Name : Professor Ts. Dr. Noreffendy Tamaldin

Date : December 5, 2020.....



DEDICATION

To my beloved late mother, late father, and my family.



ABSTRACT

Hydrogen technology and its application as renewable energy shows growing interest due to its carbon free and high calorific value. The hydrogen production via electrolysis has been well known in wet cell as well as dry cell system that can produce Hydrogen-Hydrogen-Oxygen (HHO) gas. In both HHO generators design, uses perforated electrode plates, resulting in erosion at the edges of the plate thus cause current leakage between the electrode plates and overheating. In the wet cell system, the electrodes are submerged in a liquid electrolyte thus requires high energy, cause rise in temperature, produce unstable HHO gas and triggered safety issue. The dry cell system uses only liquid electrolyte between the electrodes but also suffer from discontinuity of HHO gas production, high energy requirements and temperature increased therefore need Pulse Width Modulation (PWM) to regulate the power supplied. This study aims to overcome the above problems with both cell design. Therefore, the objectives are to design and development of a Novel hybrid HHO by integrating both wet and dry cell concept, to characterize the SS316L plate for optimum H₂ production and to evaluate HHO generator with real engine for performance and emission evaluation. In integrating the wet and dry cell concept, the best features of HHO cell were identified and developed to take advantage of its benefits such as material selection, plate configurations, electrolyte pH level, safety features, cooling circulation and assembly. SS316L plate have been selected with sizing and number of plate determination was performed via experiments. Then, surface treatment for SS316L electrode plate was performed by grinding to a specific roughness and polishing for uniformity. Its surface quality was later characterized and experimented with respect to HHO gas production before and after the treatment until reached optimum specification found in the ranged of 1.0-1.5 µm and 50g of KOH. Finally, the newly developed HHO cell were tested in Yamaha 150 hp/2560 cc marine as well as 30hp/150 cc motorcycle engine for validation. The results for SS316L electrolyzer plate before the treatment was approximately 1.0 - 2.0 µm and reduced to 1.0 -1.5 µm after the treatment therefore meeting the desired specification. The electrodes before treatment, produce is 847.46 ml/min of HHO gas with 14 V, 8.038 Amp while after treatment showed 11% increase in HHO gas at 961.54 ml/min with 14 V, 8.594 Amp. The marine engines show a fuel consumption saving of around 20-30% and temperatures were maintained below 40°C. The motorcycle test shows increase in engine performance with 0.4% power, 0.89% torque and reduction of emission include CO 25.49%, CO₂ 34%, NOx 80.92% and HC 30%. Based on the result obtained, the newly developed integrated HHO generator have proven to be more durable, stable and produce optimized HHO gas capable of reducing fuel consumption, improving engine power and torque as well as significant emission reduction. The patented HHO cooling system have proven to maintain its working temperature well below 40°C which allow longer operation and less maintenance. This finding is showing promising future for the Novel hybrid HHO generator in the internal combustion engine. Its potential in transportation as well as energy industry have wider applications especially in the sustainable energy development initiative launched around the globe.

**REKA BENTUK HIBRID NOVEL SEL PENJANA HHO UNTUK MENINGKATKAN
PRESTASI DAN PELEPASAN ENJIN.**

ABSTRAK

Teknologi hidrogen dan aplikasinya sebagai tenaga boleh diperbaharui menunjukkan minat peningkatan kerana bebas karbon dan nilai kalori yang tinggi. Pengeluaran hidrogen melalui elektrolisis telah terkenal dalam sel basah dan juga sistem sel kering yang boleh menghasilkan gas Hidrogen-Hydrogen-Oksigen (HHO). Dalam kedua-dua reka bentuk penjana HHO, menggunakan plat elektron berlubang, mengakibatkan hakisan pada tepi plat lantas menyebabkan kebocoran arus antara plat elektron dan terlalu panas. Dalam sistem sel basah, elektron terendam dalam elektrolit cecair justeru memerlukan tenaga yang tinggi, menyebabkan kenaikan suhu, menghasilkan gas HHO yang tidak stabil dan mencetuskan isu keselamatan. Sistem sel kering menggunakan elektrolit cecair hanya di antara elektron tetapi juga mengalami ketakselarangan pengeluaran gas HHO, keperluan tenaga yang tinggi dan suhu meningkat oleh itu memerlukan Modulasi Lebar Nadi (PWM) untuk mengawal kuasa yang dibekalkan. Kajian ini bertujuan untuk mengatasi masalah di atas dengan kedua-dua reka bentuk sel. Oleh itu, objektifnya adalah untuk mereka bentuk dan membangunkan HHO hibrid Novel dengan menyepadukan kedua-dua konsep sel basah dan kering, untuk mencirikan plat SS316L untuk pengeluaran H_2 yang optimum dan untuk menilai penjana HHO dengan enjin sebenar untuk penilaian prestasi dan pelepasan. Dalam menyepadukan konsep sel basah dan kering, ciri terbaik sel HHO telah dikenal pasti dan dibangunkan untuk memanfaatkan faedahnya seperti pemilihan bahan, konfigurasi plat, tahap pH elektrolit, ciri keselamatan, penyejukan dan pemasangan. Plat SS316L telah dipilih dengan saiz dan penentuan bilangan plat dilakukan melalui eksperimen. Kemudian, rawatan permukaan untuk plat elektron SS316L dilakukan dengan mengisar kepada kekasaran tertentu dan menggilap untuk keseragaman. Kualiti permukaannya kemudiannya dicirikan dan dicuba berkenaan dengan pengeluaran gas HHO sebelum dan selepas rawatan sehingga mencapai spesifikasi optimum yang terdapat dalam julat $1.0 - 1.5 \mu\text{m}$ dan 50g KOH . Akhirnya, sel HHO yang baru dibangunkan telah diuji dalam enjin Yamaha $150 \text{ hp}/2560 \text{ cc}$ marin dan motosikal $30\text{hp}/150 \text{ cc}$ untuk pengesahan. Keputusan untuk plat elektrolisis SS316L sebelum rawatan adalah kira-kira $1.0 - 2.0 \mu\text{m}$ dan dikurangkan kepada $1.0 - 1.5 \mu\text{m}$ selepas rawatan oleh itu memenuhi spesifikasi yang dikehendaki Elektron sebelum rawatan, menghasilkan adalah 847.46 ml/min gas HHO dengan 14 V , 8.038 Amp manakala selepas rawatan menunjukkan peningkatan 11% dalam gas HHO pada 961.54 ml/min dengan 14 V , 8.594 Amp . Enjin marin menunjukkan penjimatan penggunaan bahan api sekitar $20-30\%$ dan suhu dikekalkan di bawah 40°C . Ujian motosikal menunjukkan peningkatan dalam prestasi enjin dengan kuasa 0.4% , tork 0.89% dan pengurangan pelepasan termasuk CO 25.49% , CO_2 34% , NOx 80.92% dan HC 30% . Berdasarkan hasil yang diperoleh, penjana HHO bersepadu yang baru dibangunkan telah terbukti lebih tahan lama, stabil dan menghasilkan gas HHO yang dioptimumkan yang mampu mengurangkan penggunaan bahan api, meningkatkan kuasa dan tork enjin serta pengurangan emisi yang ketara. Sistem penyejukan HHO yang dipatenkan telah terbukti dapat mengekalkan suhu kerjanya di bawah 40°C yang membolehkan operasi lebih lama dan kurang penyelenggaraan. Penemuan ini menunjukkan masa depan yang menjanjikan untuk penjana HHO hibrid Novel dalam enjin pembakaran dalaman. Potensinya dalam pengangkutan serta industri tenaga mempunyai aplikasi yang lebih luas terutamanya dalam inisiatif pembangunan tenaga mampan yang dilancarkan di seluruh dunia.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful.

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to the Universitas Nasional (UNAS) and Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform. My utmost appreciation goes to my main supervisor, Professor Ts. Dr. Noreffendy Tamaldin, Universiti Teknikal Malaysia Melaka (UTeM) for all his support, advice and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered. Also, to my co-supervisor, Dr. Ahmad Kamal Mat Yamin, Universiti Teknikal Malaysia Melaka (UTeM) who constantly supported my journey. My special thanks go to Professor Nanna Suryana Herman, Dr. El Amry Bermawi Putera and Professor Dr. Eko Sugiyanto, M.Si for all the help and support I received from them.

Last but not least, from the bottom of my heart gratitude to my beloved wife, Nurhabibah, for her encouragements and who has been the pillar of strength in all my endeavors. My eternal love also to all my children, Anna, Farisah, and Farizan Shidqi, for their patience and understanding. I would also like to thank my beloved parents for their endless support, love and prayers. Finally, thank you to all the individual(s) who had provided me the assistance, support and inspiration to embark on my study.

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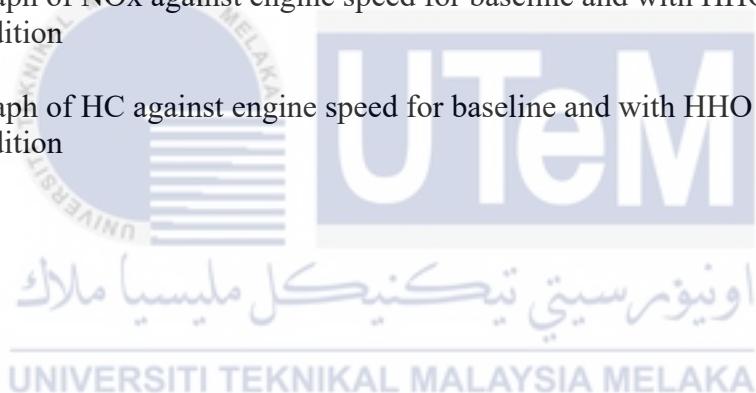
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LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|----------------------|---|
| BHP | - Brake Horse Power |
| BSFC | - BSFC Brake Specific Fuel Consumption |
| BTE | - Brake Thermal Efficiency |
| CC | - Cubic Capacity |
| CO | - Carbon Monoxide |
| CO ₂ | - Carbon Dioxide |
| CH ₄ | - Methane |
| DAQ | - Data Acquisition System |
| DC | - Direct Current |
| NOx | - Nitrogen Oxide |
| HC | - Hydrocarbon |
| HHO | - Hydrogen-Hydrogen-Oxygen |
| HP | - Horse Power |
| HTES | - High-Temperature Electrolysis of Steam |
| I | - Current (A) |
| ICE | - Internal Combustion Engine |
| KOH | - Potassium Hydroxide |
| LHVH | - Lower heating value of hydrogen gas (MJ/kg) |
| LHVd | - Lower heating value of diesel fuel (MJ/kg) |
| <i>m_f</i> | - Total mass flow rate of fuel (kg/s) |
| <i>m_H</i> | - Total mass flow rate of hydrogen gas (kg/s) |

| | |
|------------------|--|
| m_d | - Total mass flow rate of diesel fuel (kg/s) |
| N | - Engine Speed (rpm) |
| NaHCO_3 | - Natrium Bicarbonate |
| HDPE | - High Density Polyethylene |
| P | - Engine power (kW) |
| PEM | - Proton Exchange Membrane |
| R | - Resistance (Ω) |
| R_a | - The average of a set of individual measurements of a surfaces peaks and valleys in μm (According to ASME B46.1) |
| SS316L | - Stainless Steel Grade 316 Low Carbon Contents |
| T | - Torque (Nm) |
| V | - Volume flow rate of fuel (m^3/s) |
| V | - Voltage (V) |
| ρ_H | - Density of hydrogen (kg/m^3) |
| ρ_d | - Density of Diesel (kg/m^3) |
| R_a | - Roughness value |
| ZCLC | - Zero Current Leak Cell |

LIST OF PUBLICATIONS

Journal with impact factor

Indexed journal

- a. Ajat, S., Noreffendy, T., Ahmad, K.M.Y., and Ridzuan, M.M., 2020. The Correlation of Surface Morphology to The HHO Generator Gas Production. *International Journal of Mechanical and Production, Engineering Research and Development*, 10(3), pp. 13787-13794.
- b. Ajat, S., Noreffendy, T., Ahmad, K.M.Y., Fadzli, M.A., Hafidz, M.Z., and Gomezgani, N., 2020. Performance Analysis of Biodiesel Engine by Addition of HHO Gas as a Secondary Fuel. *Jurnal Tribologi*, 26, pp. 120-134.

Non-indexed journal

1. Ajat, S., Irfan, N., Kiki, R.L., and Vekky, R.V., 2020. The Effect of Addition of HHO Gas to the Gasoline Engine on Emissions and Fuel Consumption. *Jurnal Ilmiah GIGA*, 23(1), pp. 8-19.

Conference proceedings

1. Ajat, S., Noreffendy, T., Ahmad, K.M.Y., Fadzli, M.A., 2018. Optimization of HHO generator zero current leak cell (ZCLC) model characteristics for improve gas productivity. *2018 Proceedings of Mechanical Engineering Research Day*. (WOS indexed).

2. Ajat, S., Eva, M.H., Noreffendy, T., Ahmad, K.M.Y., 2018. Principle of Generator HHO Hybrid Multistack Type Production Technologies to Increase HHO Gas Volume. *2018 International Conference of Education on Standardization (ICES2018)*, National Standardization Body, Republic of Indonesia. (WOS indexed).
3. Purwondho, R. and Sudrajat, A., 2021,. Research on the Effect of SS316L Electrode Plate Treatment on HHO Gas Production Performance. In *IOP Conference Series: Earth and Environmental Science* (Vol. 794, No. 1, p. 012021). July, IOP Publishing.

Research exhibition award

1. Ajat, S., Noreffendy, T., and Ahmad, K.M.Y., 2020. Removal of Carbon Deposit Build Up Using HHO Engine Cleaning System. *Participants in the 29th International Invention, Innovation and Technology Exhibition Malaysia - ITEX2020* - Gold award
2. Ajat, S., Noreffendy, T., and Ahmad, K.M.Y., 2019. Removal of Carbon Deposit Build Up Using HHO Engine Cleaning System. *Participants in the UTeM Exhibition 2019 - UTeMEx2017* - Gold award
3. Ajat, S., Noreffendy, T., and Ahmad, K.M.Y., 2018. The design of standard HHO gas flow and pH level measuring equipment with low cost on HHO hybrid generator. *Participants in the 29th International Invention, Innovation and Technology Exhibition Malaysia - ITEX2018* - Gold award
4. Ajat, S., Noreffendy, T., and Ahmad, K.M.Y., 2017. The Novel Hybrid Design of HHO Cell Generator for Improved Engine Performance and Emission. Participants in the UTeM Exhibition 2017 - UTeMEx2017 - Gold award

Intellectual Property (IP)

1. Malaysia Patent Application titled “Hydrogen Cell Cooling Circulation” on 14/05/2018, and has been allocated with Application Number PI 2018000707. Patent Filed by UTeM.
2. Indonesia Patent Application titled “Insulator Seal Spacer System Using of HDPE Materials on Hybrid HHO Generator with Stainless Steel 316l Plate without Hole”. Application Number: S00201800156. 2018.

