UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF EMBEDDED SYSTEM TO CONTROL MOTORIZED CNG-AIR MIXER FOR DIESEL DUAL-FUEL ENGINE

ABDULWAHAB A. ABDULRAHMAN AL-SAADI

DESIGN AND DEVELOPMENT OF EMBEDDED SYSTEM TO CONTROL MOTORIZED CNG-AIR MIXER FOR DIESEL DUAL-FUEL ENGINE

By

ABDULWAHAB A. ABDULRAHMAN AL-SAADI

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

February 2018

DEDICATION

This work dedicated to

My Mother
A gentle soul who spirted me with kindness
An illiterate lady who taught me to trust in Allah

My Father
My hero
Prof. Dr. Shiekh Abdulrazaq Abdulrahman Al-Saadi
My role model who permanently supported me financially and spiritually

My Brothers and Sisters
Whom always been noble and supportive

My Father-In-Law and Mother-In-Law
Whom encouraged me to believe in myself

My Wife and my Children
My stress releasers
The spirit of my heart and my pen, whom continuously offered me happiness

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

DESIGN AND DEVELOPMENT OF EMBEDDED SYSTEM TO CONTROL MOTORIZED CNG-AIR MIXER FOR DIESEL DUAL-FUEL ENGINE

By

ABDULWAHAB A. ABDULRAHMAN AL-SAADI

February 2018

Chairman : Ishak Bin Aris, PhD
Faculty : Engineering

The world grows in population with rising demand for energy. The environment is much affected by emissions from excessive usage of energy sources, particularly the fossil fuels in transportation, which are producing high amount of Carbon Dioxide (CO_2). Concerns over pollution and climate change issues are motivating researchers and engineers to find robust solutions. One of the challenges is to discover low CO_2 emission fuels. For instance, natural gas emits up to 70% percent less CO_2 than diesel fuel. As a result, the invention of dual-fueled engines took place as a reliable alternative. Diesel-CNG dual fuel (DDF) engine is one of the best approaches to protect the environment, reduce energy consumptions and eliminate pollution. Since it uses diesel and compressed natural gas (CNG), the DDF engine shows very low emissions compared to conventional diesel engine.

The DDF engine for the commercial vehicles uses manual CNG-air mixer to partially replace the diesel fuel with the CNG. The proposed motorized CNG-air mixer (MCM) was designed and fabricated to replace the manually actuated CNG-air mixer which needs further optimizations. However, the proposed MCM mixer offers the ability to electronically control and optimize CNG-air mixture and eventually enhance its quality.

The objective is to design, simulate and develop an embedded system to control the opening and closing of CNG inlet valve inside the proposed MCM mixer. This embedded system aimed to control bi-polar stepper motor in bi-directional technique by using the high-speed and low-cost PIC16F887 microcontroller chip. The stepper motor was derived by the ASTROSYN P403 stepper motor driver. The inputs of the system were from potentiometers/ sensors.

The complete integrated system was simulated and tested as a prototype. The embedded system has 100% accuracy of the simulation and experimental results of PWM1 and PMW2 duty cycle. It has good accuracy up to 75% when comparing the simulation and the experimental response of settlement delay time of RPM input signals.

As a conclusion, the success in operating and controlling the stepper motor in the proposed MCM mixer indicated that the embedded system was successfully designed, simulated and developed.

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

REKA BENTUK DAN PEMBANGUNAN SISTEM TERBENAM UNTUK MENGAWAL PENGADUN CNG-UDARA BERMOTOR BAGI ENJIN DIESEL DWI BAHAN BAKAR

Oleh

ABDULWAHAB A. ABDULRAHMAN AL-SAADI

Februari 2018

Pengerusi : Ishak Bin Aris, PhD
Fakulti : Kejuruteraan

Pertambahan populasi dunia yang seiring dengan peningkatan permintaan untuk tenaga menyebabkan peningkatan pencemaran. Natijahnya, alam sekitar mengalami kesan buruk hasil penggunaan sumber tenaga berlebihan, terutamanya Karbon Dioksida hasil daripada penggunaan bahan api fosil dalam sektor pengangkutan. Pada masa yang sama, kebimbangan terhadap pencemaran dan perubahan iklim mendorong para penyelidik dan jurutera untuk mencari kaedah penyelesaian yang mantap. Salah satu cabarannya ialah untuk menemui bahan api yang menghasilkan kuantiti Karbon Dioksida yang rendah. Sebagai contoh, gas asli menghasilkan Karbon Dioksida 70% kurang berbanding dengan bahan api diesel. Oleh itu, penciptaan enjin dengan dwi bahan bakar merupakan satu alternatif yang boleh dipercayai.

Enjin dwi bahan bakar diesel-CNG adalah salah satu daripada pendekatan terbaik untuk melindungi alam sekitar, mengurangkan penggunaan bahan api dan menghapuskan pencemaran. Memandangkan enjin ini menggunakan diesel dan gas asli mampat (CNG), enjin DDF menghasilkan pelepasan yang sangat rendah berbanding dengan enjin diesel konvensional. Enjin DDF untuk kenderaan komersil menggunakan pengadun CNG-udara untuk menggantikan bahan api diesel dengan CNG secara rasional.

Pengadun CNG-udara bermotor telah dicadangkan untuk menggantikan pengadun CNG-udara manual yang memerlukan pengoptimuman lanjutan. Walau bagaimanapun, pengadun MCM yang dicadangkan berupaya untuk mengawal dan mengoptimumkan campuran CNG-udara secara elektronik dan meningkatkan kualitinya.

Objektif kajian ini adalah untuk merekabentuk, mensimulasi dan membangunkan sistem terbenam yang mengawal pembukaan dan penutupan injap masuk CNG di dalam pengadun MCM. Sistem terbenam ini bertujuan untuk mengawal motor stepper dwikutub dalam teknik dwiarah dengan menggunakan cip pengawal mikro PIC16F887 yang berkelajuan tinggi dengan kos rendah. Motor stepper dipacu oleh cip pemandu motor ASTROSYN P403. Input system adalah daripada potentiometers/pengesan yang menjana isyarat analog yang berubah-ubah dalam julat 0v hingga 5v.

Sistem bersepadu yang sempurna telah disimulasikan dan diuji sebagai model. Simulasi ini sepadan dengan bacaan sebenar semasa sistem ini diuji. Motor stepper memberikan tindak balas yang sangat baik terhadap arahan daripada pengawal mikro untuk menggerakkan injap pengadun MCM ke hadapan dan ke belakang, di mana akhirnya, output yang diingini telah diperolehi.

Sebagai kesimpulan, kejayaan dalam mengendalikan dan mengawal motor stepper dalam pengadun MCM novel ini menunjukkan bahawa sistem terbenam ini telah berjaya direkabentuk, disimulasi dan dibangunkan.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Beneficent, the Most Merciful

First of all, I would like to express my depth thankful to my helpful and supportive supervisor Prof. Dr. Ishak Bin Aris. I always believed that this work would not been accomplished without his inspiration and guidance.

Special thank go to my supervisory committee Assoc. Prof. Ir. Dr. Mohd. Khair Bin Hassan who always supported me through the journey of this project.

Heartfelt thanks goes to my colleagues and friends: brother Saber (from Sudan), brother Muneer (form India), brother Ibraheem (from Nigeria), brother Akeel and Shaker (from Iraq) and Assoc. Prof. Dr. Mohammed Abdulhakeem Al-Saadi who has stood by my side and supported me.

I certify that a Thesis Examination Committee has met on 28 February 2018 to conduct the final examination of Abdulwahab A. Abdulrahman Al-Saadi on his thesis entitled "Design and Development of Embedded System to Control Motorized CNG-Air Mixer for Diesel Dual-Fuel Engine" in accordance with the Universities and University Colleges 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.

Members of the Thesis Examination Committee were as follows:

Noor Izzri bin Abdul Wahab, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Siti Anom binti Ahmad, PhD
Associate Professor
Malaysian Research Institute On Ageing
Universiti Putra Malaysia
(Internal Examiner)

Mohd Razali bin Daud, PhD
Senior Lecturer
Universiti Malaysia Pahang
Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 26 April 2018

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Ishak bin Aris, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Khair b. Hassan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: ________________________ Date: ____________________

Name and Matric No.: Abdulwahab A. Abdulrahman Al-Saadi, GS41114

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ______________________

Name of Chairman of Supervisory Committee: Professor Dr. Ishak bin Aris

Signature: ______________________

Name of Member of Supervisory Committee: Associate Professor Dr. Mohd Khair b. Hassan

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A/D	analog-to-digital converter
AFR	air to fuel ratio
CI engine	compression-ignition engine
CNG	compressed natural gas
DC	direct-current
DDF engine	diesel-CNG dual fuel engine
H/C ratio	hydrogen to carbon ratio
IC	integrated circuit
IC engine	internal-combustion engine
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MCM	motorized CNG-air mixer
NGV	natural gas vehicle
RPM	revolution-per-minute
SI engine	spark-ignition engine

CHAPTER 1

INTRODUCTION

1.1 Background

Internal combustion engines and their fuels have been exposed to continuously developments and enhancements since the first proposed paraffin engine - similar to diesel nowadays- which was invented by the English inventor Herbert Akroyd Stuart in 1885. A few years later, in 1892, he constructed the first operating engine that uses the diesel as its fuel (Challen & Baranescu, 1999; Hussein A. Mahmood, Nor Mariah. Adam, B. B. Sahari, & S. U. Masuri, 2017).

Governments want to reduce relaying on conventional fuels because it is well known that the reserves of oil are being exhausted at a worrying ratio (Sangeeta et al., 2014). Furthermore, the burning of fuels used nowadays by transport sector contributes seriously to environmental pollution that threatens every existence life on our planet earth (Trumbo & Tonn, 2016). The seriously environmental pollution issue around the globe has encouraged scientists and researchers to develop a low emission and high efficient fuels (Khan, Yasmin, & Shakoor, 2015).

Numerous alternative fuels have been introduced into the transportation sector e.g. Compressed Natural Gas (CNG), propane, Liquefied Petroleum Gas (LPG), hydrogen, bio-diesel and fuel cells. Especially, the diesel engines because of their high emission rate. Alternative fuels had been added to the diesel engines to optimize their exhaust emissions and their performance. One of the best proposed alternative fuels is CNG because of its availability in most of the countries around the world, economically compared to diesel, relatively clean burning fuel and adaptability to the diesel engines (Khan, Yasmeen, Khan, Farooq, & Wakeel, 2016; Khan, Yasmeen, Shakoor, et al., 2016; Talal F. Yusaf, 2010; Trumbo & Tonn, 2016).

The CNG fuel cannot be totally replaced with diesel fuel for the diesel engine because there is no spark ignition to burn the CNG alone. Unlike the diesel fuel, natural gas is not an auto-ignited sort of fuels. This leads to the invention of the diesel-CNG dual fuel (DDF) engine. The DDF engine uses diesel fuel as spark ignition to burn the mixture of CNG and air inside the combustion chamber –the engine's cylinder (Mahmood, Adam, Sahari, & Masuri, 2016).

There are several methods of injecting CNG into the diesel engines such as direct injection and pre-mixed mixture of CNG and air through a CNG-air mixer/ inert which is normally located at the inlet stream of the intake manifold of the engine (Park, Lee, Lim, Choi, & Kim, 2013).

The CNG-air mixer produces a mixture of atmospheric air and natural gas. Finally, the CNG-air mixture is ready to be burned by the pressure of the piston and spraying of certain quantity of diesel (Liu, Yang, Wang, Ouyang, & Hao, 2013).

1.1 Problem statement

The world grows in population with rising demand for energy, the pollution increases. Consequently, the environment is much affected by emissions from excessive usage of energy sources, particularly the fossil fuels in transportation, which are producing high amount of Carbon Dioxide (CO_2). Concerns over pollution and climate change are motivating researchers and engineers to find robust solutions. One of the challenges is to discover low CO_2 emission fuels. For instance, natural gas emits up to 70% percent less CO_2 than diesel fuel. As a result, the invention of diesel-CNG dual-fuel (DDF) engines took place as a reliable alternative.

The mixture of CNG and air is one of the most important parameter in controlling DDF engines. If the mixture is very lean or very rich, it will cause weak engine performance or it may leads to failure of combustion. CNG-air mixer should produce an air-fuel ratio (AFR) that meets the required ratio for a good engine operation (Ishida et al., 2001; Kadirgama et al., 2008; Park et al., 2013).

There are several methods of mixing CNG and air, one of them is the manually actuated CNG-air mixer. This mixer is located at the inlet air stream of the intake manifold of the DDF engines. Since, this sort of mixer that used in the DDF engine vehicles is producing much quantity of hazardous gases due to the low quality mixture of the CNG and air.

Based on the research and investigation held by (Hussein Adel Mahmood, Nor Mariah Adam, B. B. Sahari, & S. U. Masuri, 2017), they have stated that the conventional manual CNG-air mixer needs further optimization with regards to homogeneity of the CNG-air mixture. They have proposed a new CNG-air mixer. The proposed CNG-air mixer had been designed and developed to enhance the CNG-air mixture.

The proposed CNG-air mixer requires a stepper motor to operate. However, there is no automatic system to actuate the proposed mixer. (Hussein Adel Mahmood et al., 2017). It allows the optimum quantity of natural gas to be mixed with air in DDF engine. Therefore, enhancement should be done to the proposed mixer to enhance homogeny of the CNG and air. This could be done by actuating the proposed mixer via stepper motor. The stepper motor is controlled through an embedded system.

1.2 Research objectives

This research aims to design and develop an embedded system to control the proposed motorized CNG-air mixer for DDF engine. The objectives include:

i- To design and develop accurate and low cost embedded system to control stepper motor based system for the proposed motorized CNG-air mixer for DDF engine.
ii- To design and simulate a program algorithm using the PIC16F887 microcontroller that controls the valve position of the proposed motorized CNG-air mixer.

1.3 Research scope

The DDF engine for the commercial vehicles uses CNG-air mixer to rationally replace the diesel fuel with the CNG. The motorized CNG-air mixer (MCM) was designed and fabricated by (Hussein Adel Mahmood et al., 2017) to replace the manually actuated CNG-air mixer which needs further optimizations. However, the proposed MCM mixer offers the ability to electronically control and optimize CNG-air mixture and eventually enhance its quality.

This research aims to enhance the homogenous of the mixture of CNG and air that carried out by the motorized CNG-air Mixer. Therefore, the objective is to design and develop embedded system to control a stepper motor. The stepper motor is used to open and close CNG inlet valve precisely. The opening of the CNG inlet valve is governed by screw shaft inside MCM. The valve blends the CNG gas with air at the inlet of the proposed motorized CNG-air mixer.

1.4 Thesis layout

This thesis is divided into five chapters that cover detailed stages of the research, though introduction, setting of problem statement and objectives, literature review, methodology and material, results and discussions, conclusions and recommendations for future works.

Chapter 1 shapes the background, the problem statement and objectives of this project. Chapter 2 summarizes the literature review. Chapter 3 demonstrates the methodology and materials used to achieve the objectives of the project. Chapter 4 illustrates the results and discusses them. Chapter 5 shows general conclusions and provides recommendations for future works.

REFERENCES

Al-Saadi, A. A. A., & Aris, I. B. (2015, May 31). *CNG-diesel dual fuel engine: A review on emissions and alternative fuels.* Paper presented at the 2015 10th Asian Control Conference (ASCC), Kota Kinabalu, Malaysia.

Alla, G. A., Soliman, H., Badr, O., & Rabbo, M. A. (2000). Effect of pilot fuel quantity on the performance of a dual fuel engine. *Energy Conversion and Management, 41*(6), 559-572.

Alla, G. A., Soliman, H., Badr, O., & Rabbo, M. A. (2002). Effect of injection timing on the performance of a dual fuel engine. *Energy Conversion and Management, 43*(2), 269-277.

Amazon. Microcontrollers. Retrieved from https://www.amazon.com/ref=nav_logo

American Gas Association, A. A. (1993). *AGA NGV 2:1992 Basic Requirements For Compressed Natural Gas Vehicle (ngv) Fuel Containers*. New York, USA: American Gas Association.

Burnett, R. T., Cakmak, S., Brook, J. R., & Krewski, D. (1997). The role of particulate size and chemistry in the association between summertime ambient air pollution and hospitalization for cardiorespiratory diseases. *Environmental health perspectives, 105*(6), 614.

Cahyono, B., & Bakar, R. (2015). Air-fuel Mixing and Fuel Flow Velocity Modeling of Multi Holes Injector Nozzle on CNG Marine Engine. *Procedia Earth and Planetary Science, 14*, 101-109.

Challen, B., & Baranescu, R. (1999). *Diesel engine reference book*: McFarland.

Cheenkachorn, K., Poompipatpong, C., & Ho, C. G. (2013). Performance and emissions of a heavy-duty diesel engine fuelled with diesel and LNG (liquid natural gas). *Energy, 53*, 52-57.

Cho, H. M., & He, B.-Q. (2007). Spark ignition natural gas engines—A review. *Energy Conversion and Management, 48*(2), 608-618.

Clark, N. N., Gautam, M., Rapp, B. L., Lyons, D. W., Graboski, M. S., McCormick, R. L., . . . Norton, P. (1999). *Diesel and CNG transit bus emissions characterization by two chassis dynamometer laboratories: Results and issues* (0148-7191). Retrieved from

Colvile, R. N., Hutchinson, E. J., Mindell, J. S., & Warren, R. F. (2001). The transport sector as a source of air pollution. *Atmospheric Environment, 35*(9), 1537-1565.

CytronTechnology. Microcontrollers Retrieved from https://www.cytron.io/

Dahake, M., Patil, S., & Patil, S. (2016). Performance and Emission Improvement through Optimization of Venturi Type Gas Mixer for CNG Engines. *International Research Journal of Engineering and Technology (IRJET), 03*(01), 994 - 999.

Dondero, L., & Goldemberg, J. (2005). Environmental implications of converting light gas vehicles: the Brazilian experience. *Energy Policy, 33*(13), 1703-1708.

Egúsquiza, J., Braga, S., & Braga, C. (2009). Performance and gaseous emissions characteristics of a natural gas/diesel dual fuel turbocharged and aftercooled engine. *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 31*(2), 142-150.

Element14. Microcontrollers Retrieved from http://my.element14.com/

Energy, T. U. S. D. o. (2017). Alternative Fuels Data Center, The U.S. Department of Energy. Retrieved from https://www.afdc.energy.gov/vehicles/natural_gas.html

Frailey, M., Norton, P., Clark, N. N., & Lyons, D. W. (2000). *An evaluation of natural gas versus Diesel in medium-duty buses* (0148-7191). Retrieved from

G. William, K. (2000). The role of Natural Gas in the Transportation Sector. *The World Bank, Washington, DC.*

Goyal, P., & Sidhartha. (2003). Present scenario of air quality in Delhi: a case study of CNG implementation. *Atmospheric Environment, 37*(38), 5423-5431.

Hesterberg, T. W., Lapin, C. A., & Bunn, W. B. (2008). A Comparison of Emissions from Vehicles Fueled with Diesel or Compressed Natural Gas. *Environmental Science & Technology, 42*(17), 6437-6445. doi:10.1021/es071718i

Ishida, A., Nishimura, A., Uranishi, M., Kihara, R., Nakamura, A., & Newman, P. (2001). The development of the ECOS-DDF natural gas engine for medium-duty trucks: exhaust emission reduction against base diesel engine. *JSAE Review, 22*(2), 237-243.

Jahirul, M. I., Masjuki, H. H., Saidur, R., Kalam, M. A., Jayed, M. H., & Wazed, M. A. (2010). Comparative engine performance and emission analysis of CNG and gasoline in a retrofitted car engine. *Applied Thermal Engineering, 30*(14–15), 2219-2226.

Jayaratne, E. R., Ristovski, Z. D., Meyer, N., & Morawska, L. (2009). Particle and gaseous emissions from compressed natural gas and ultralow sulphur diesel-fuelled buses at four steady engine loads. *Science of The Total Environment, 407*(8), 2845-2852.

Kadirgama, K., Noor, M. M., Rahim, A. R. N. A., Devarajan, R., Rejab, M. R. M., & Zuki, N. M. (2008, March 8-10, 2008). *Design and Simulate Mixing of Compressed Natural Gas with Air in a mixing device.* Paper presented at the Malaysian Technical Universities Conference on Engineering and Technology (MUCET2008), Putra Palace, Perlis, Malaysia.

Kado, N. Y., Okamoto, R. A., Kuzmicky, P. A., Kobayashi, R., Ayala, A., Gebel, M. E., . . . Zafonte, L. (2005). Emissions of Toxic Pollutants from Compressed Natural Gas and Low Sulfur Diesel-Fueled Heavy-Duty Transit Buses Tested over Multiple Driving Cycles. *Environmental Science & Technology, 39*(19), 7638-7649.

Kannan, N., & Vakeesan, D. (2016). Solar energy for future world: - A review. *Renewable and Sustainable Energy Reviews, 62*, 1092-1105.

Khan, M. I., Yasmeen, T., Khan, M. I., Farooq, M., & Wakeel, M. (2016). Research progress in the development of natural gas as fuel for road vehicles: A bibliographic review (1991–2016). *Renewable and Sustainable Energy Reviews, 66*, 702-741.

Khan, M. I., Yasmeen, T., Shakoor, A., Khan, N. B., Wakeel, M., & Chen, B. (2016). Exploring the potential of compressed natural gas as a viable fuel option to sustainable transport: A bibliography (2001–2015). *Journal of Natural Gas Science and Engineering, 31*, 351-381.

Khan, M. I., & Yasmin, T. (2014). Development of natural gas as a vehicular fuel in Pakistan: Issues and prospects. *Journal of Natural Gas Science and Engineering, 17*, 99-109.

Khan, M. I., Yasmin, T., & Shakoor, A. (2015). Technical overview of compressed natural gas (CNG) as a transportation fuel. *Renewable and Sustainable Energy Reviews, 51*, 785-797.

Knowledgebase, N. G. (2017). Current Natural Gas Vehicle Statistics. Retrieved from http://www.iangv.org/current-ngv-stats/

Lanni, T., Frank, B. P., Tang, S., Rosenblatt, D., & Lowell, D. (2003). *Performance and emissions evaluation of compressed natural gas and clean diesel buses at New York City's Metropolitan Transit Authority* (0148-7191). Retrieved from

Liu, J., Yang, F., Wang, H., Ouyang, M., & Hao, S. (2013). Effects of pilot fuel quantity on the emissions characteristics of a CNG/diesel dual fuel engine with optimized pilot injection timing. *Applied Energy, 110*, 201-206.

Mahmood, H. A., Adam, N. M., Sahari, B., & Masuri, S. (2016). Investigation on the Air-Gas Characteristics of Air-Gas Mixer Designed for Bi-Engines. *International Journal of Applied Engineering Research, 11*(12), 7786-7794.

Mahmood, H. A., Adam, N. M., Sahari, B. B., & Masuri, S. U. (2017). Design of Compressed Natural Gas-Air Mixer for Dual Fuel Engine Using Three-Dimensional Computational Fluid Dynamics Modeling. *Journal of Computational and Theoretical Nanoscience, 14*(7), 3125-3142. doi:10.1166/jctn.2017.6605

Mahmood, H. A., Adam, N. M., Sahari, B. B., & Masuri, S. U. (2017). New Design of a CNG-H2-AIR Mixer for Internal Combustion Engines: An Experimental and Numerical Study. *Energies, 10*(9), 1373.

Martins, A. A., Rocha, R. A. D., & Sodré, J. R. (2014). Cold start and full cycle emissions from a flexible fuel vehicle operating with natural gas, ethanol and gasoline. *Journal of Natural Gas Science and Engineering, 17*, 94-98.

Matic, D. (2006). *Global opportunities for natural gas as a transportation fuel for today and tomorrow, IGU study group—natural gas for vehicles.* Paper presented at the Proceeding of the 23rd World Gas Conference, International Gas Union (IGU), Amsterdam, The Netherlands.

McTaggart- Cowan, G., Reynolds, C., & Bushe, W. (2006). Natural gas fuelling for heavy- duty on- road use: current trends and future direction. *International journal of environmental studies, 63*(4), 421-440.

Mena-Carrasco, M., Oliva, E., Saide, P., Spak, S. N., de la Maza, C., Osses, M., & Molina, L. T. (2012). Estimating the health benefits from natural gas use in transport and heating in Santiago, Chile. *Science of The Total Environment, 429*, 257-265.

MicrochipTechnologyInc. (2007). PIC16F882/883/884/886/887 Data Sheet 28/40/44-Pin, Enhanced Flash-Based 8-Bit CMOS Microcontrollers with nanoWatt Technology. U.S.A.: Preliminary.

Noor, M., Kadirgama, K., Devarajan, R., Rejab, M., & Yusaf, T. (2008). *Development of a high pressure compressed natural gas mixer for a 1.5 litre CNG-diesel dual engine.* Paper presented at the Proceedings of the National Conference on Design and Concurrent Engineering (DECON), Melaka, Malaysia.

NSCEP, N. S. C. f. E. P. (June 2015). *Class 8 CNG / Diesel System Cost Analysis*. USA: United States Environmental Protection Agency (EPA) Retrieved from https://www.epa.gov/history.

Park, C., Lee, S., Lim, G., Choi, Y., & Kim, C. (2013). Effect of mixer type on cylinder-to-cylinder variation and performance in hydrogen-natural gas blend fuel engine. *International Journal of Hydrogen Energy, 38*(11), 4809-4815.

Prati, M. V., Mariani, A., Torbati, R., Unich, A., Costagliola, M. A., & Morrone, B. (2011). Emissions and Combustion Behavior of a Bi-Fuel Gasoline and Natural Gas Spark Ignition Engine. *SAE Int. J. Fuels Lubr., 4*(2), 328-338. doi:10.4271/2011-24-0212

Ristovski, Z., Morawska, L., Ayoko, G. A., Johnson, G., Gilbert, D., & Greenaway, C. (2004). Emissions from a vehicle fitted to operate on either petrol or compressed natural gas. *Science of The Total Environment, 323*(1), 179-194.

Rounce, P., Tsolakis, A., & York, A. (2012). Speciation of particulate matter and hydrocarbon emissions from biodiesel combustion and its reduction by aftertreatment. *Fuel, 96*, 90-99.

Sadeghinezhad, E., Kazi, S. N., Sadeghinejad, F., Badarudin, A., Mehrali, M., Sadri, R., & Reza Safaei, M. (2014). A comprehensive literature review of bio-fuel performance in internal combustion engine and relevant costs involvement. *Renewable and Sustainable Energy Reviews, 30*, 29-44.

Sangeeta, Moka, S., Pande, M., Rani, M., Gakhar, R., Sharma, M., & Bhaskarwar, A. N. (2014). Alternative fuels: An overview of current trends and scope for future. *Renewable and Sustainable Energy Reviews, 32*, 697-712.

Semin, R. A. B. (2008). A technical review of compressed natural gas as an alternative fuel for internal combustion engines. *American J. of Engineering and Applied Sciences, 1*(4), 302-311.

Shahraeeni, M., Ahmed, S., Malek, K., Van Drimmelen, B., & Kjeang, E. (2015). Life cycle emissions and cost of transportation systems: Case study on diesel and natural gas for light duty trucks in municipal fleet operations. *Journal of Natural Gas Science and Engineering, 24*, 26-34.

Sindhu, S., Nehra, V., & Luthra, S. (2017). Solar energy deployment for sustainable future of India: Hybrid SWOC-AHP analysis. *Renewable and Sustainable Energy Reviews, 72*, 1138-1151.

Singh, S., Krishnan, S., Srinivasan, K., Midkiff, K., & Bell, S. (2004). Effect of pilot injection timing, pilot quantity and intake charge conditions on performance and emissions for an advanced low-pilot-ignited natural gas engine. *International journal of Engine research, 5*(4), 329-348.

Talal F. Yusaf, D. R. B., Khalid H. Saleh, B.F. Yousif. (2010). CNG-diesel engine performance and exhaust emission analysis with the aid of artificial neural network. *Applied Energy*(87), 9.

Trumbo, J. L., & Tonn, B. E. (2016). Biofuels: A sustainable choice for the United States' energy future? *Technological Forecasting and Social Change, 104*, 147-161.

Vehicles, N. G. (2014). Seizing the Opportunity, A Regional Roadmap for Deployment, Northwest Gas Association.

Wei, L., & Geng, P. (2016). A review on natural gas/diesel dual fuel combustion, emissions and performance. *Fuel Processing Technology, 142*, 264-278.

WikimediaCommons. (8 February 2010). Animation of a simplified stepper motor Retrieved from https://en.wikipedia.org/wiki/Stepper_motor

Yeh, S. (2007). An empirical analysis on the adoption of alternative fuel vehicles: The case of natural gas vehicles. *Energy Policy, 35*(11), 5865-5875.

Yousefi, A., Birouk, M., & Guo, H. (2017). An experimental and numerical study of the effect of diesel injection timing on natural gas/diesel dual-fuel combustion at low load. *Fuel, 203*, 642-657.

Yusaf, T., & Mohammed, Z. (2000). *Development of a 3D CFD model to investigate the effect of the mixing quality on the CNG-diesel engine performance.* Paper presented at the Proceedings of the International Conference and Exhibition and Natural Gas Vehicles, Yokohama, Japan.

Zhao, J., & Melaina, M. W. (2006). Transition to hydrogen-based transportation in China: lessons learned from alternative fuel vehicle programs in the United States and China. *Energy Policy, 34*(11), 1299-1309.