Journal of Engineering and Applied Sciences 14 (21): 7788-7794, 2019
ISSN: 1816-949X

A Review of Gas Emission Effect due to Air Fuel Ratio on Diesel Engine

Semin, Gusma Hamdana Putra and Putri Dyah Setyorini
Department of Marine Engineering, Institute Teknologi Sepuluh Nopember,
60111 Surabaya, Indonesia
seminits@yahoo.com

Abstract: Air pollution is one of main challenging issues now a days that some researchers has been trying to solved. There are so many aspects that can cause air pollution and the biggest one is from marine transportation. The emissions from marine transportation are mostly from the engine propulsion which is using diesel engine as their driver. Diesel consumption is responsible for serious air pollution which includes Nitrogen Oxides (NOx), Hydrocarbon (HC), Carbon monoxide (CO) and some Particulate Matter (PM). Therefore, efforts to tackle harmful gases from diesel engines is very important because with such efforts can prevent the pollution level increases. In general, an engine will operate when completed elements of combustion that include air, fuel and heat. This composition is called air/fuel ratio which shows a comparison the amount of air and fuel to be incorporated into the engine combustion chamber. Due to the large impact of air/fuel ratio to engine output generated in this study will be explained in more detail whatever the impact of the effect of the composition of the air/fuel ratio both the engine and the output of the engine, especially, the effect of the emission.

Key words: Diesel consumption, air pollution, engine combustion, engine propulsion, emissions, transportation

INTRODUCTION

Air pollution is one of main challenging issues now a days that some researchers has been trying to solved. In recent years, many complex engine subsystems and control technologies have been introduced to meet the demands of strict regulations and the competitive market too. The emissions from marine transportation are responsible for 50% of air pollution in this world (Al-Himyari *et al.*, 2014) which is from engine that used by the vessels. Some vessels are mostly using diesel engine for their driver. Fundamental investigations concerning ignition systems in gas engines are sparse with respect the availability of optical data, most studies focus on engine performance and emission investigations and the influence of a multitude of effects such as gas composition, ignition timing, combustion chamber geometry, etc. (Schlatter, 2015). For diesel engines, combustion control is one of the most effective approaches for reducing engine exhaust emissions Di Leo (2015).

Diesel consumption is responsible for serious air pollution which includes Nitrogen Oxides (NOx), Hydrocarbon (HC), Carbon monoxide (CO) and some Particulate Matter (PM) discharged from the combustion chamber Geng *et al.* (2017) but depends on (Challen and Baranescu, 1999). There are some emissions that regulated and unregulated the regulated consist of carbon dioxide, carbon monoxide, unburned hydrocarbons, nitrogen oxides, odour and particulates. And unregulated emissions such as sulphur oxides, aldehydes, ammonia, benzene, polyclinic aromatic hydrocarbons and nitropolycyclic aromatic hydrocarbons. Therefore, efforts tackle harmful gases from diesel engines is very important because with such efforts can prevent the pollution level increases.

In general, an engine will operate when completed elements of combustion that include air, fuel and heat. In mixing system, air (in atmosphere) will be entered in engine both with pull of a turbocharger or without turbo charger (Challen and Baranescu, 1999). The amount of air enters the combustion chamber is strongly influenced model of the air inlet because of this model will affect both the speed, pressure up a potential incoming air and burn completely (Ibrahim *et al.*, 2008). In mixing the fuel and air, so, be able burn requires precise composition. This composition is called air/fuel ratio which shows a comparison the amount of air and fuel be incorporated in the engine combustion chamber. Air/fuel ratio is a very important element which has a large effect on combustion

Corresponding Author: Semin, Department of Marine Engineering, Institute Teknologi Sepuluh Nopember, 60111 Surabaya, Indonesia, seminits@yahoo.com

process in the engine combustion chamber and the effectiveness value for engine performance (Ismail and Abu Bakar, 2007).

Due the large impact of air/fuel ratio engine output generated in this study will be explained in more detail whatever, the impact of the effect of the composition of the air/fuel ratio both the engine and the output of the engine. In explanation of the air/fuel ratio is viewed from some of the literature in the form of books, journals and the results of the proceedings that has been published.

MATERIALS AND METHODS

Air/fuel and fuel/air ratio: Accurate air/fuel ratio control is vital high engine performance, good vehicle drivability and low emissions. From the air aspect, containts of oxygen that enters in the combustion area will affect the combustion process such as temperature, heat energy and the pressure by Semin *et al*. (2008). Two components enter in calculating air/fuel ratio, namely, the amount of fresh air and the amount of fuel (Chatlatanagulchai *et al*., 2010) in diesel engine, air/fuel ratio has a very important that be able influence on combustion process (Chughtai *et al*., 2002) on performance by Ma *et al*. (2008) and on exhaust gas (emission) Li *et al*. (2016). Figure 1 the ilustration of effect (emissions) due air-fuel ratio.

According to Tan (2014), the air/fuel flow can be calculated with the values which have either a mole or mass units while research using mole means references

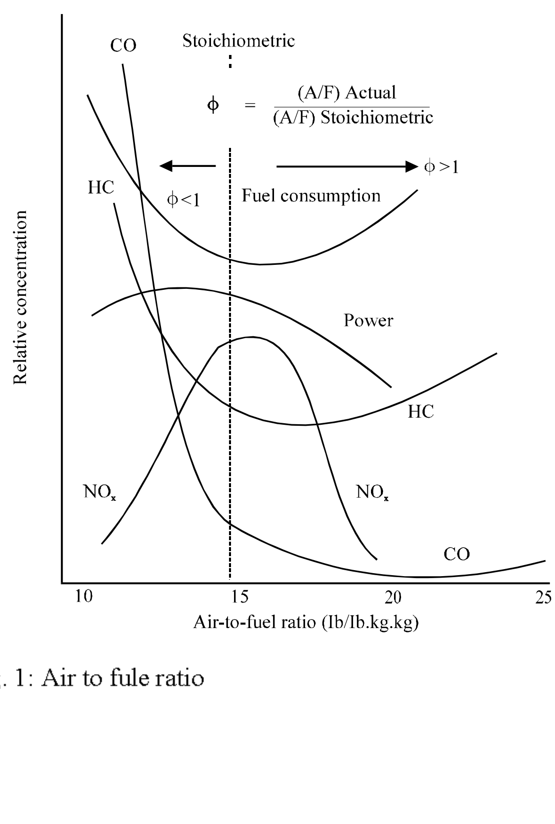

Fig. 1: Air to fule ratio

used in composition of the mixture between air and fuel in form of units of moles and vice versa in units of mass. Formulation for air/fuel ratio in units of mole is as follows:

$$\left(\frac{A}{F}\right) = \frac{n_a}{n_f} = \frac{\left(\sum n_i\right)a}{\left(\sum n_i\right)f} \quad (1)$$

Where:

n = Mole amount subscript
a = Stand for air
f = Stand for fuel

Based on calculations above, we can know the composition of the air/fuel ratio which will affect in particular on gas emissions. In addition to term air/fuel ratio, there is also a term fuel/air ratio that means composition of fuel with air which will also have an impact like composition of air/fuel ratio Ganesan (2007). Formulation for fuel/air ratio in units of mole is as follows:

$$\left(\frac{F}{A}\right) = \frac{n_f}{n_a} = \frac{\left(\sum n_i\right)f}{\left(\sum n_i\right)a} \quad (2)$$

Thus, the air/fuel ratio are grouped in several ranges of composition to identify that give an impact on combustion process, the results of performance and emissions. The groupings are rich air conditions, stoichiometric air condition and lean air condition to the explanation will be described.

Rich mixtures: A condition in which the content of air is more than content of fuel will have an impact of incomplete combustion due to too much oxygen and will not burn, so, go wasted along with the exhaust gas.

Stoichiometric mixtures: A condition in which composition of balance between air and fuel, so as to produce a perfect combustion and optimum performance results where in this condition is also often called stoichiometric combustion.

Lean mixtures: A condition in which the composition of the air entering the combustion chamber is less than the fuel, so that, the combustion process can not be perfect and there is still residual fuel is vented along with the exhaust gas.

Having obtained the calculation of the composition of air/fuel ratio it can be searched an number of air/fuel ratio which is calculated by stoichiometric conditions or commonly called the equivalent ratio and is denoted Φ Stone (1992):

$$\Phi = \frac{\text{Stoichiometric air/Fuel ratio}}{\text{Actual air/Fuel ratio}} \quad (3)$$

If the result that according to Challen and Baranescu (1999):

- $\Phi = 1,47$ is a stoichiometric mixtures
- $\Phi < 1,47$ is a rich mixtures
- $\Phi > 1,47$ is a lean mixtures

Increasing the composition air/fuel ratio could be done in several ways. Air/fuel ratio can change due to modification process from the amount of air into combustion chamber. As research Ismail and Abu Bakar (2007) where to make changes to get valve lift air capacity varies. Wherein the valve lift shortened condition (valve open slightly) will affect the capacity of air becomes small and the effect on air/fuel ratio and vice versa, if the extended valve lift. By modifying both a design flow of intake of air to modify the shape of combustion will produce different combustion efiesensi although the composition of the incoming air as of the same as is done by Abu Bakar and Ismail (2007) for the design and calculation of the fuel flow correction entered to find the highest efficiency.

Air fuel ratio also can be a method that can raising the coefficient of excess air are proposed to reduce the thermal load and accordingly enhance the performance of diesel engine Wei and Xie (2012). It can be observed that the brake thermal efficiency is increases nearby the richest condition (AFR≅35) and then decreases with increases of AFR and speed which is the air-fuel ratio was varied from stoichio metric limit to a lean limit. By Rahman *et al.* (2009) says that a lean mixture is one in which the amount of fuel is less than stoichiometric mixture. This leads to fairly easy to get an engine start.

There are some strategies for minimalizing the emissions such as controlling air fuel ratio. Controlling the Air-Fuel Ratio (AFR) is necessary because the AFR has an enormous impact on the effectiveness of the fuel and reduction of emissions Al-Himyari *et al.* (2014). Hence, in this study will explain about the controlling emissions form the air fuel ratio because the AFR has a great effect on effectiveness of the fuel and the decrease of emissions compared to all other engine control factors.

RESULTS AND DISCUSSION

Emissions in diesel engine: Diesel engine capable of producing gas operation in which some of the gas composition are pollutants (pollution). As these gases among which Nitrogen Oxides (NOx), Carbon monoxide (CO), Carbon dioxide (CO_2) and Hydrocarbons (HC) Wei and Geng (2016). On this section will explain the impact of air/fuel ratio to exhaust gas (emission).

Nitrogen Oxides (NOx): Nitrogen oxide is a gas exhaust from diesel engines were divided into two groups NO and NO_2 which is the highest element of the combustion in the combustion chamber Wei and Geng (2016). In both cases, the nitrogen oxides are generated by reaction of nitrogen and oxygen from air. This mechanism is highly dependent on temperature, linearly dependent on oxygen atom concentration and independent of the fuel type. The emission of nitric oxides from diesel is one of the more difficult ones to control, since, control techniques are normally tend to increase other emissions or fuel consumption Challen and Baranescu (1999). Some studies related to the impact of air/fuel ratio for NOx contents will be described below.

In research conducted by Ma *et al.* (2008) the effect of different volumes of Natural Gas (NG) by adding the composition of the Hydrogen (H_2) and rotated in a steady performance. Where this study using 6-cylinder engine with addition of hidorgen composition from 0-50% and variation of ratio air/fuel from 0.7-1.3. Of some variable ratio of air/fuel is used at a ratio of 1.11 to be played at 800 RPM indicate that NOx levels tend to be low. This is because the engine is operated at low load. When the reinjection time was changed from 0-35° TDC, the results obtained are NOx increases. This is due to the injection of an increasingly long time, so that, the temperature in the combustion chamber is increasing.

Based on research of Nguyen *et al.* (2011)about the effect of the split injection and addition of oxygen composition of 20-23% on diesel engines. The ratio of air/fuel used is equal to 1.00. From the study found that levels of NOx increases as the addition of oxygen to the composition of combustion chamber. This is because more oxygen is added to composition the greater the energy produced during the combustion process, so that, NOx levels to increase with increasing temperature in the combustion chamber.

According to research of Dinesha *et al.* (2014), about the effect of oxygen addition to performance, combustion process and exhaust gas (emission). The ratio of air/fuel is 1.3 with the addition of variable oxygen of 3-5 and 7%. The results obtained from this study ischange in levels of NOx produced due to influence of load where the greater load received by engine generated NOx content increases. This is because the amount of fuel injected into combustion process, so that, temperature in combustion chamber is rise and NOx result is also increases. Besides of oxygen concentration addition, also, resulted in increased levels of NOx due to the burning of oxygen generates heat energy which will increase the temperature in combustion chamber of diesel engine.

Research on the comparison of air flow technology, Lateral Swirl Combustion System (LSCS) with Double Swirl Combustion System (DSCS) have been carried out by Li *et al*. (2016). By variation of air/fuel ratio from 1.3-2.2 have an impact on combustion process, performance and exhaust gas (emission). The result is that NOx levels of system LSCS higher than DSCS and NOx levels were increase if the air/fuel ratio variable increasen. This is because of the difference between DSCs and LSCS is on after treatment and increasing consequent in ratio composition explained that composition also increases the oxygen that burned in combustion chamber. Therefore, the incereasing of NOx levels is not significant.

In the study conducted by Hegab *et al*. (2017) is about the analysis of demand and fuel supply where this research used two types of machines as a comparison: Conventional Diesel Operation (CDO) and Dual Fuel Operation (DFO) with a ratio of air/fuel is around 1.73. The variable that used for ranging load is from 0-100% by analyzing the performance, the combustion process and exhaust gas (emissions). The results obtained are NOx levels in DFO higher than CDO due to the addition of natural gas (oxygen concentration) which affects the combustion process in combustion chamber of diesel engine. Besides the greater load change also affects the increased levels of NOx due to increase reinjection time, so that, temperature in combustion chamber increases.

The conclusions that can be drawn from studies above, namely, the composition of air/fuel ratio ranging (0.5-1.7) showed an increase of NOx produced but the composition of 1.7 to above is not an increase and tend to be stable. In this case, commensurate with the principle of air/fuel ratio by Heywood (1988) which affects the content of NOx. It will decrease if air/fuel ratio reach the rich condition because there was so much oxygen content and misfire.

Hydrocarbons (HC): Hydrocarbons occur due to incomplete combustion process which occurs when temperature in combustion chamber is small (under 1,200 K) causing oxidation in combustion chamber. As for the effect of the occurrence of hydrocarbons is an air/fuel ratio Wei and Geng (2016). Some studies related to the impact of air/fuel ratio for HC contents will be described below.

Research on performance and exhaust gas (emissions) resulting from the Natural Gas Dual Fuel Engine (NGDF) and Conventional Diesel Fuel (DFC) has been done by Shioji *et al*. (2001). Where one study to see the effect of natural gas addition in the levels of Hydrocarbons (HC) generated from engine. With some variation the ratio of air/fuel that is 0.2-1.0 and a variety of RPM is 1200 RPM and 2000 RPM. The results obtained from these studies that there are significant differences between NGDF by DFC where the levels of hydrocarbons produced NGDF larger than the DFC. Then the HC levels were increased in 0.1-0.5 air/fuel ratio and in 0.5-1 decreased levels of HC. This is because the ratio of air/fuel oxygen content of 0.1-0.5 in combustion chamber and temperature a bit, so that, energy generated is small and result in inhibited oxidation processes which is contrary to conditions on ratio of air/fuel 0.5-1 which resulted in decreased levels generated HC.

In research conducted by Dinesha *et al*. (2014) on oxygen concentration addition in combustion chamber diesel engines of 3-5 and 7% which will be tested on performance, the combustion process to flue gas with the ratio of air/fuel is 1.3. The fuel used is diesel fuel and bio-fuel mixture that is B20M10 (20% cardanol; 10% methanol and 70% diesel fuel). The results were obtained among which the increasing graph of hydrocarbons when the engine is operated from the load of 30-100%. However, when compared on a variable concentrations of oxygen, the fuel 100% diesel fuel, B20M10; B20M10 with addition of oxygen concentration of 3-7% then produced a declining graph. This is due to the oxygen content which further adds to energy in combustion chamber during combustion process, so that, the temperature increases and result in inhibited oxidation processes, so, decreases HC levels.

Research on the addition of emulsion along with oxygen concentration in diesel engines by looking at performance, combustion process and exhaust gases have been carried out by Baskar and Kumar (2017). In the test, the diesel engine with a compression ratio of 17:1 is configured in a composition of air/fuel ratio 1.82 which is played on load of 20, 40, 60, 80 and 100% in 1500. The RPM results achieved, namely, their chart elevated levels of Hydrocarbons (HC). This is due to delay combustion, resulting in increased heat energy in the premix combustion conditions and the faster oxidation process, so that, the levels of HC is also increased.

Related research conducted by Hegab *et al*. (2017) which is about the comparison between Conventional Diesel Operation (CDO) with Dual Fuel Operation (DFO) on performance and exhaust gas (emission) using variable loads ranging from 0-100% and the ratio of air/fuel used is 1.73. It aims to obtain data about the ideal conditions between the demand and needs in an operational condition. The results obtained are about levels of hydrocarbons produced namely HC levels from DFO is higher than levels of HC from CDO it is because of the characteristics of DFO is to add the composition of the air that is natural gas. A little load conditions of temperature conditions in the combustion chamber is small; slowdown in the combustion process leading to high levels of HC.

From some of research reviews can be concluded that air/fuel ratio also had an impact on hydrocarbons contents it happens because it is influenced in addition to air and fuel composition that occurs in combustion chamber and thermal energy and temperature also affected by load and length of time reinjection Dinesha *et al*. (2014). However, according to Challen and Baranescu (1999), unburned hydrocarbons is not associated with the air/fuel ratio because in principle these hydrocarbons based on the load and speed. Hence, this only affected by the volume of nozzles with varying levels of HC generated will decrease. By Aydin and Ogut (2017) was done their research and the result is HC emissions increased as the engine load increased due to the increase of fuel consumption at higher loads.

Carbon dioxide (CO_2): Carbon dioxide emissions are controlled entirely by the amount of fuel burnt, the more fuel being burnt, the higher the carbon dioxide emissions Wei and Geng (2016). Carbon dioxide emission should however be maximized for a given amount of fuel being burnt, since, this indicates that combustion is as complete as possible. It has been researched that in lean combustion condition, CO_2 emission was controlled by air/fuel equivalence ratio; While in rich combustion condition, CO_2 emission is offset by CO emission Wu *et al*. (2004). Some studies related to the impact of air/fuel ratio for CO_2 contents will be described below.

In the study conducted Lounici *et al*. (2014) is on test performance and exhaust (emissions) of natural gas-diesel dual fuel. Where the diesel dual fuel engine used consisted of a 4-cylinder engine with a compression ratio of 18:1 and the composition ratio of the fuel/air at 1.1. Variables are created as reference testing of variable loads ranging from 0-100% load. The result obtained is that with the change in load resulting CO_2 levels also increased. This is because the amount of fuel more, so, due to imperfect combustion process also completely oxidized.

Then research on the comparison between diesel mode with natural-gas dual fuel diesel combustion process testing and exhaust gases produced have been done by Abdelaal and Hegab (2012). In this study, the engine that used are single-cylinder engine with a compression ratio of 16.5: 1 and the composition of the air/fuel fuel used for diesel mode 1.43 and 1.63 for natural-gas dual fuel load variations between 0-100%. The results are based on a variable load that increasing the levels of CO_2 obtained also increased. This is because the highest burden of the presence of hydrocarbons that burn completely, so that, the increased CO_2 levels. This applies to both types of both diesel engines and natural gas-mode dual fuel engine.

From the research it can be concluded that the relationship between air/fuel ratio against a very small CO_2 levels do. This is because of several studies on air/fuel ratio turns rarely discuss on CO_2 levels impact. This can be attributed to principle of CO_2 formation gas that comes from successfully oxidized carbon is formed by Heywood (1988). In this case, the combustion process of engine can be said to be perfect, so that, when load increased variable CO_2 content increased too. In addition, based on research by Wei and Geng (2016) which is inversely proportional relationship between the hydrocarbon and CO_2 where CO_2 from burning of hydrocarbons. Therefore, when the hydrocarbon decreases the CO_2 levels will rise and vice versa.

Carbon monoxide (CO): Carbon monoxide is a dangerous gas because it is a pollutant which formed due to the inability to burn completely in the combustion chamber Wei and Geng (2016). Formation of CO results from oxidation of fuels consisting of carbon and hydrogen with oxygen. CO is formed as a result of the disintegration of the resulting products by Aydin and Ogut (2017). Some studies related to the impact of air/fuel ratio for CO contents will be described below.

Research on the effect of hydrogen content addition and comparison of air from diesel engines to be tested on performance and exhaust (emissions) has been done by Ma *et al*. (2008). Where the engine is rotated at a constant speed of 800 RPM, the air ratio of 0.7-1.3 and variation load at-100%. The result is that at a constant speed and constant load but air ratio to change showed a decrease in the chart of which 14000 ppm CO levels at a ratio of 0.7 and 1000 ppm at a ratio of 1.25. This is because the increase in the composition of the air enters the combustion chamber, so that, the combustion process is perfect for being able to oxidize fuel overall.

Research carried out by Ma *et al*. (2007) is about the analysis of thermal efficiency and exhaust gas from hydrogen addition content in CNG engines. Where the engine that used in this study are 6-cylinder engine with a compression ratio of 10.5: 1 by comparing the ratio of variable air/fuel from 0.8-2.8. From the results obtained that the drop in graph to the lowest levels of CO in the ratio of 1.8-2.0 and increase in ratio of 2.0 and above. This is due to the perfect combustion process, so that, carbon is able oxidized by the composition air/fuel ratio. Then for ratios above 2.0 can be seen that the inability of carbon to be oxidized because too rencahnya levels of air/fuel and unable to oxidize completely and resulted in increased CO levels.

From research conducted by Hegab *et al.* (2017) is about increasing oxygen levels and tested the performance the combustion process and exhaust gases from diesel engines were added to cardanol fuel. The engine is operated on composition ratio of 1.3 and played on load variation of 0-100% with diesel fuel fuel serta B20M10 (Cardanol 20%; 10% methanol, diesel fuel 70%) were added to oxygen content of 3-5 and 7%. Where the results obtained, namely an increase in CO levels in an increasingly large load variations. This is because more fuel amount that injected into combustion chamber, so, it does not burn completely. In addition to fuel graph of B20M10; B20M10 3%; B20M10, B20M10, 5 and 7%, greater CO levels than diesel fuel. This is because the effect of fuel element. But with rise between fuel, increasing oxygen content in combustion chamber is able to reduce the CO content produced

Then research on the comparison between Conventional Diesel Operation (CDO) with Dual Fuel Operation (DFO) with combustion process and exhaust gases testing have been carried out by Hegab *et al.* (2017). Where to varying load at 0-100% and use air/fuel ratio 1.72. The results obtained by comparison of CO level in air/fuel of 1.7 is higher than the DFO CDO. This is due to the added element of gas, so that, the impact of temperature reduction and concentration ratio of air/fuel increases, causing the length of combustion process and fuel is not burned and come out with exhaust gases. In addition to an increase in levels of CO in the CDO where it occurs in an increasing load conditions because it detracted from rich mixture, so that, the smoke zone.

From a review of research above can be seen that the levels of CO gas combustion products is not perfect because the Hydrocarbon (HC) could not completely oxidized to CO_2. The reason is because one of them influences the comparison of air/fuel. The oxygen content is an element that is very influential for oxidation process which takes place during combustion process of the composition of air (oxygen) are included in the less fuel will result in defective process of oxidation. This is in accordance with the principle of Challen and Baranescu (1999) in which the CO levels will decrease when the composition of the air/fuel stoichiometric approach.

CONCLUSION

Based on studies can be concluded that there is a correlation either directly or indirectly. The direct effect of the composition air/fuel ratio is like Nitrogen Oxide (NOx); Hydro Carbons (HC) and Carbon monoxide (CO) in the other hand, the indirect influence is Carbon dioxide (CO_2). In both of engine (diesel engines and diesel dual fuel engine) has an emission which strongly influenced air/fuel ratio composition, load and RPM that affect the combustion process either temperature, pressure, duration of injection of up to the resulting of heat energy.

REFERENCES

Abdelaal, M.M. and A.H. Hegab, 2012. Combustion and emission characteristics of a natural gas-fueled diesel enginewith EGR. Energy Convers. Manage., 64: 301-312.

Abu Bakar, S.R. and A.R. Ismail, 2007. Air flow analysis of four stroke direct injection diesel engines based on air pressure input and l/d ratio. Res. J. Applied Sci., 2: 1135-1142.

Al-Himyari, B.A., A. Yasin and H. Gitano, 2014. Review of air fuel ratio prediction and control methods. Asian J. Appl. Sci., 2: 471-478.

Aydin, F. and H. Ogut, 2017. Effects of using ethanol-biodiesel-diesel fuel in single cylinder diesel engine to engine performance and emissions. Renewable Energy, 103: 688-694.

Baskar, P. nd A.S. Kumar, 2017. Experimental investigation on performance characteristics of a diesel engine using diesel-water emulsion with oxygen nriched air. Alexandria Eng. J., 56: 137-146.

Challen, B. and R. Baranescu, 1999. Diesel Engine Reference Book. 2nd Edn., Butterworth-Heinemann Ltd,? Oxford, England, UK., ISBN:9780750621762, Pages: 682.

Chatlatanagulchai, W., S. Rhienprayoon, K. Yaovaja and K. Wannatong, 2010. Air/fuel ratio control in diesel-dual-fuel engine by varying throttle, EGR valve and total fuel (No. 2010-01-2200). SAE Technical Paper, SAE International Automotive, Michigan, USA.https://www.sae.org/publications/technical-papers/content/2010-01-2200/

Chughtai, A.R., J.M. Kim and D.M. Smith, 2002. The effect of air/fuel ratio on properties and reactivity of combustion soots. J. Atmos. Chem., 43: 21-43.

Di Leo, R., 2015. Methodologies for Air-Fuel ratio and trapped mass estimation in diesel engines using the in-cylinder pressure measurement. Energy Procedia, 82: 957-964.

Dinesha, P., V. Nayak and P. Mohanan, 2014. Effect of oxygen enrichment on the performance, combustion and emission of single cylinder stationary CI engine fueled with cardanol diesel blends. J. Mech. Sci. Technol., 28: 2919-2924.

Ganesan, V., 2007. Internal Combustion Engine-V Ganeshan. Tata McGraw-Hill Publishing, New Delhi, India.

Geng, P., E. Cao, Q. Tan and L. Wei, 2017. Effects of alternative fuels on the combustion characteristics and emission products from diesel engines: A review. Renew. Sustainable Energy Rev., 71: 523-534.

Hegab, A., A. La Rocca and P. Shayler, 2017. Towards keeping diesel fuel supply and demand in balance: Dual-fuelling of diesel engines with natural gas. Renewable Sustainable Energy Rev., 70: 666-697.

Heywood, J.B., 1988. Internal Combustion Engine Fundamentals. McGraw-Hill, New York, USA., ISBN:9780071004992, Pages: 930.

Ibrahim, M.I.N., S.R.A. Bakar and A.R. Ismail, 2008. In-Cylinder flow through piston-port engines modeling using dynamic mesh. J. Applied Sci. Res., 4: 58-64.

Ismail, A.R. and S.R. Abu Bakar, 2007. Valve flow discharge coefficient investigation for intake and exhaust port of four stroke diesel engines. J. Eng. Applied Sci., 2: 1807-1811.

Li, X., H. Zhou, L. Su, Y. Chen and Z. Qiao *et al*., 2016. Combustion and emission characteristics of a lateral swirl combustion system for DI diesel engines under low excess air ratio conditions. Fuel, 184: 672-680.

Lounici, M.S., K. Loubar, L. Tarabet, M. Balistrou and D.C. Niculescu *et al*., 2014. Towards improvement of natural gas-diesel dual fuel mode: An experimental investigation on performance and exhaust emissions. Energy, 64: 200-211.

Ma, F., J. Wang, Y. Wang, Y. Wang and Y. Li *et al*., 2008. Influence of different volume percent hydrogen/natural gas mixtures on idle performance of a CNG engine. Energy Fuels, 22: 1880-1887.

Ma, F., Y. Wang, H. Liu, Y. Li and J. Wang *et al*., 2007. Experimental study on thermal efficiency and emission characteristics of a lean burn hydrogen enriched natural gas engine. Intl. J. Hydrogen Energy, 32: 5067-5075.

Nguyen, L.D.K., N.W. Sung, S.S. Lee and H.S. Kim, 2011. Effects of split injection, oxygen enriched air and heavy EGR on soot emissions in a diesel engine. Intl. J. Automot. Technol., 12: 339-350.

Rahman, M.M., M.M. Noor, K. Kadirgama, M.R.M. Rejab, 2009. Study of air fuel ratio on engine performance of direct injection hydrogen fuelled engine. Eur. J. Sci. Res., 30: 506-513.

Schlatter, S., 2015. Experimental and numerical characterization of enhanced ignition systems for large bore gas engines. Ph.D Thesis, ETH Library, Zürich, Switzerland.

Semin, A.R.I., R.A. Bakar and I. Ali, 2008. Steady-state and transient simulation of gas flow temperature of intake port engine. J. Appl. Sci. Res., 4: 767-777.

Shioji, M., T. Ishiyama, M. Ikegami, S. Mitani and H. Shibata, 2001. Performance and exhaust emissions in a natural-gas fueled dual-fuel engine. JSME. Intl. J. Ser. B. Fluids Therm. Eng., 44: 641-648.

Stone, R., 1992. Introduction to Internal Combustion Engines. 2nd Edn., The Macmillan Press Ltd, London, UK., ISBN:978-0-333-55084-7, Pages: 574.

Tan, Z., 2014. Air Pollution and Greenhouse Gases: from Basic Concepts to Engineering Applications for Air Emission Control. Springer, Berlin, Germany, ISBN:978-981-287-211-1, Pages: 481.

Wei, H.J. and H.B. Xie, 2012. Effects of coefficient of excess air on the combustion performance of marine two-stroke diesel engine. Appl. Mech. Mater., 214: 114-118.

Wei, L. and P. Geng, 2016. A review on natural gas/diesel dual fuel combustion, emissions and performance. Fuel Process. Technol., 142: 264-278.

Wu, C.W., R.H. Chen, J.Y. Pu and T.H. Lin, 2004. The influence of air-fuel ratio on engine performance and pollutant emission of an SI engine using ethanol-gasoline-blended fuels. Atmos. Environ., 38: 7093-7100.