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Research Article

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The effect of some design and operational parameters on the emitted NOx from Spark ignition engine fueled by natural gas

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Abstract Iraq is suffering from a major deterioration in infrastructure and a significant shortage of energy supplies despite the richness of this country with crude oil and natural gas. To date, millions of cubic feet of natural gas associated with crude oil extracted from wells are being burned. This wealth is wasted and can be used in the best form as an alternative fuel for gasoline in the existing engines of cars with some modifications. In this study we investigated the NOx concentrations emitted by a change in some design factors (compression ratio) and operational factors (engine speed, equivalence ratio and spark timing).
Results showed that the most significant effect in NOx concentrations was the equivalence ratio, with NOx concentrations on the lean and rich sides increasing near the equivalence ratio from the lean side. Retarding spark timing causes a sharp drop in NOx concentrations in the lean side and its maximum value. The NOx concentrations increase when the engine speed increases from a low to medium speeds and then the NOx levels decrease by increasing this speed to high speeds. The increase in compression ratio increases the NOx concentrations of the rich and poor sides and causes their levels to decrease at the maximum value.

Keywords emitted NOx, four-stroke engine, natural gas

Introduction

Energy is the main engine of the economy, development and welfare of nations [1]. Hence, energy has gained importance for governments and nations. The more energy secure the community is, the more comfortable the community will be [2]. Energy is used to move vehicles, trucks and heavy transport machines, as well as trains, ships, and aircraft [3]. The fuel used to produce energy is mostly fossil fuels either oil or natural gas [4]. The governments of the world today are working to reduce dependence on oil, especially after the crushing crisis caused by the fluctuation of oil prices and led to the deterioration of the global economy [5]. The shift to renewable energy, green, alternative to oil is the best option to reduce pollution caused by oil burning and its consequences such as global warming and climate change [6]. However, to date alternative fuels have not provided the ideal fuel that can replace diesel or gasoline [7, 8]. Yes, the world is about to replace some of these fuels with bioethanol and biodiesel, but their total replacement is still far away [9-15].

The second and somewhat easier option is to operate the engines of this equipment with gas fuel such as hydrogen [16, 17], methane [18, 19], or liquefied petroleum gas [20, 21]. Hydrogen is the best of these types of fuel, as it burns to leave only water and heat in addition to a small amount of nitrogen oxides [22]. Methane is highly available in natural gas and can be sourced from other sources, most notably oil refining [23]. Methane is a very clean fuel compared to oil as its emissions from pollutants are very low compared to oil [24, 25]. Liquefied petroleum gas (LPG) is produced by refining oil, which is clean and has a higher thermal value than methane, but produces more pollutants than methane when burned [26, 27]. Hydrogen is characterized by a very high flame speed, which is the highest of all known fuels to today, while methane is characterized by a low flame speed is the lowest among the above mentioned fuels, while the liquefied petroleum gas at a speed of flame is slightly higher than the speed of gasoline flame [28-30]. Adding hydrogen to both methane and liquefied petroleum gas increases the speed of flame, while adding methane to any other fuel reduces the speed of a flame [31, 32].

Nitrogen oxides are formed in the combustion chamber due to an unbalanced reaction of oxygen and nitrogen with very high temperatures [33]. These conditions usually occur in the early stages of combustion. In the spark ignition engines, these conditions are obtained immediately after the electrical spark is initiated and the start of the combustion process (forming the flame front and extending it) [34]. In the expansion phase, the temperature of the combustion chamber decreases rapidly, causing slow reactions in the nitrogen oxides and then freezing them (in the sense of proven proportions) [35]. The risk of nitrogen oxides is when combined with water vapor to compose nitrite acids and it helps to increase ozone concentrations, which increases the erosion of materials [36]. Nitrogen oxides need adequate conditions to form abundantly. These conditions are high temperatures of more than 960°C, abundant in oxygen, and provide the time necessary to complete the oxidation process [37]. These conditions can be combined together and then increase the concentrations of NOx and when one or more of them is low, then NOx concentrations will be reduced [38]. The high flame propagation velocity as in hydrogen causes the NOx concentrations to increase when this fuel is used. In the case of methane that has low-flame speed, the NOx concentrations are lower than those of hydrogen and gasoline [39, 40]. Increasing the compression ratio increases the temperature in the combustion chamber, increasing the NOx concentrations produced [41]. The same is true when advancing the spark timing, which means giving enough time to form NOx as the combustion chamber's temperatures rises to high rates [42].

The maximum amount of NOx concentrations is obtained at an equivalence ratio close to the correct chemical ratio (stoichiometric ratio ($\text{Ø}=1$)) from the lean side ($\text{Ø}<1$) [43]. The complete and efficient fuel combustion with necessary oxygen is provided to complete this process in sufficient time, and because the maximum temperature of the combustion chamber is achieved [44]. The NOx emission rates increase with the increase of the compression ratio at a constant spark timing due to the high maximum cycle temperature within the combustion chamber. Increasing engine speed reduces the time required for nitrogen oxidation, resulting in reduced reaction and NOx emitted [45-47]. Spark timing delay is one of the best ways to reduce NOx emissions because it reduces the time required to react and reduces the temperature of the combustion chamber [48-50].

Ref. [51] indicated that the air relative humidity with the air temperature has a clear effect on the resulting NOx. Changing relative air humidity from 40 to 70% caused a 15% reduction in engine NOx. The researchers noted that reducing the air intake pressure reduces the NOx concentrations emitted and increasing the air temperature of the engine increases the resulting NOx.

Ref. [52] found that the location of the spark plug inside the combustion chamber has a clear effect on the NOx concentrations emitted, as this site affects the temperature and pressure inside the combustion chamber. The study also showed that the shape of the combustion chamber affects the emitted pollutants. As the fuel mixture becomes more volatile, more NOx is emitted, explaining that increasing the rate of disturbance increases the maximum cycle temperature. To reduce engine-generated NOx, the researchers advised recycling part of the exhaust gas in high-turbulence motors. Note that NOx rates are higher in natural gas than gasoline because of the spark timing used was to give the best torque for each air-fuel ratio. Studies have concluded that NOx emitted from natural gas combustion is less than gasoline engines when the engines operate with a fixed spark time [53-55].

Iraq suffers from severe air, water, and soil pollution because of the military operations of the numerous wars that the country has fought in the past 40 years [56, 57]. Iraq also suffers from deterioration in the infrastructure, especially oil refineries, which were hit by the American aggression in 1991 in addition to the hands of brutal terrorism since 2014 until today [58]. All this has caused the Iraqi fuel to be the worst among the world's fuels, despite the country's richness in oil and natural gas [59, 60]. Iraqi diesel contains about 10000 to 25000ppm of sulfur [61, 62], while Iraqi gasoline contains 500 ppm [63, 64], which is very high ratios that cause high pollution rates in addition to the smokeand sulfur contaminants [65]. To date, with Iraq having the world's fourth largest natural gas reserves after Russia, Iran and Qatar, the exploitation of this wealth is still very weak and the Iraqi government is still burning the amount of $ 15 million per day of natural gas associated with oil at a extraction [66]. This study attempts to explain the process of using natural gas as fuel for motor vehicles and the impact of some design factors such as compression ratio and operational factors such as speed, equivalence ratio and speed on the emitted NOx.

Experimental Setup

The experiments were performed using a single-cylinder, four-stroke engine with variable compression ratio, spark timing, and air-to-fuel ratio type Ricardo E6. The motor is designed with an electric dynamometer and the engine is lubricated using an external gear pump. Engine water cooling rotates using a centrifugal pump. The engine natural gas processing system consists of natural gas cylinder equipped with a pressure regulator that contains two measures of pressure inside the cylinder and the pressure of the delivered gas. Natural gas is transferred to the engine after passing through the chocked nozzles system to measure the natural gas flow rate, even to very low rates, as the system is used as a flame trap. The amount of air entering the engine is measured by an air scale called Alock viscous flow meter connected to a flame trap and pressure differentials are measured on both sides of the device using a tilted water manometer. The engine rotation speed is measured using a tachometer. The dynamometer is used in addition to generating the torque needed to measure the power produced by the engine. The temperature of the exhaust gas is measured by a double thermocouple type B. NOx was emitted by chemical photo-dynamics, a process of light emission in a chemical reaction. All measuring devices used have been calibrated and checked for accuracy.

Tests procedure

Exhaust gas was analyzed and studied for the engine when it was under the influence of various factors including the following:

1. The effect of the compression ratio as this ratio was changed from 8: 1 to 13.5: 1 at an optimum spark timing for each equivalence ratio and when the engine speed is fixed at 1500 rpm. These experiments have been conducted for a wide range of lean and rich equivalence ratios.
2. Effect of engine speed on NOx concentrations emitted when changing the engine rotation speed by (1000, 1250, 1500, 1750, 2000, 2250, and 2500 rpm) at the higher useful compression ratio of 13:1 and the optimum spark timing and a wide range of equivalence ratios.
3. The effect of the equivalent ratio as this percentage has been changed from very lean equivalence ratios to rich equivalence ratios with the engine speed fixed at 1500 rpm and at higher useful compression ratio with optimum spark timing for each ratio.
4. Spark timing variation effect: Spark timing was provided for each equivalence ratio when operating the engine by the higher useful compression ratio and 1500 rpm.

Results and Discussions

Figure 1 shows the relationship between the equivalence ratio and the NOx levels when the compression ratio changes. NOx concentrations are at the lowest level at (Ø = 0.62) and increased by increasing the equivalence ratio. This increase in NOx rates is due to the increase in the combustion temperature, which reaches its peak near the stoichiometric ratio from the lean side at (Ø=0.945), where the combustion temperature is higher with the availability of oxygen necessary to burn most of the fuel. The NOx concentrations decrease after this percentage.

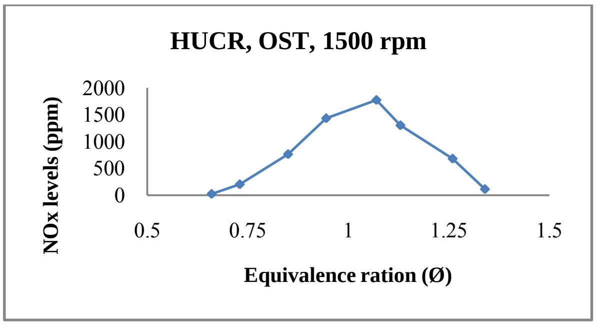

Figure 1: The effect of equivalence ratio on NOx levels

Figure 2 shows the change in NOx concentrations with the change in spark timing when the engine works with at the higher useful compression ratio and the engine speed of 1500 rpm for three selected equivalence ratios. The effect of spark timing on NOx is very clear at the equivalence ratio that gives the max value to NOx. At (Ø=0.95), NOx concentrations are as large as possible and if the spark timing was retarded by only 2.5 ° BTDC, these concentrations decrease by up to 70%. At lean equivalence ratio (Ø=0.75), NOx concentrations decreased by 89%. At a rich mixture (Ø=1.25), the effect of sparks timing is limited.

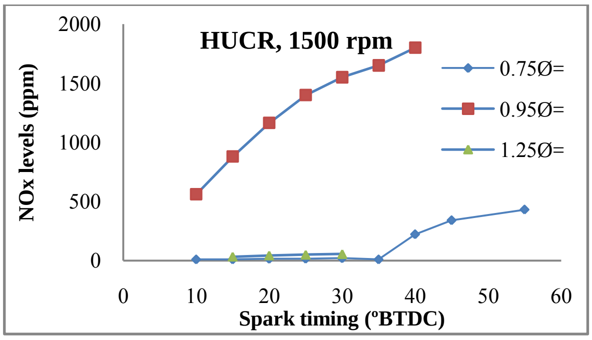

Figure 2: The effect of spark timing on NOx levels

Figure 3 illustrates the effect of the compression ratio on the NOx concentrations for a wide range of equivalent values and the speed of 1500 rpm and optimal monitoring of the sparks. Curves show the similarity of fuel behavior when increasing the compression ratio from 8: 1 to 13: 1. On the weak side, the NOX concentrations are increased by increasing the compressive ratio of equivalent (= = 0.75) and lower, and increasing in the rich side at equivalent ratios (Ø = 1.15) and higher, although the increase is limited in these two fields. Increases the compression ratio delay the optimal timing of the rust in these areas, which reduces the concentrations of Knox emitted. The effect of increasing the compression ratio reverses the effect of sparks, so the resulting NOX concentrations are the sum of these two factors.

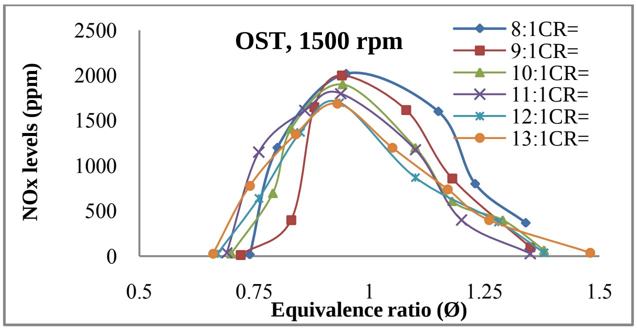

Figure 3: The effect of compression ratio variation on NOx levels for wide range of equivalence ratios

Figure 4 shows the relationship between compression ratio change and NOx concentrations. An increase in these concentrations is observed at CR=13.5 and for the four selected equivalent ratios due to the phenomenon of the knock, which caused a high rise in the temperature of the combustion chamber, although the spark timing was retarded, as the compression ratio here is the dominant factor.

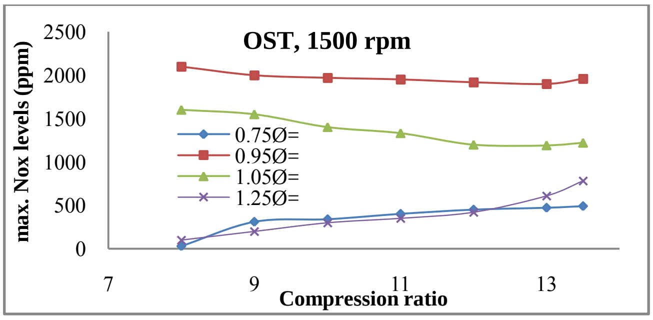

Figure 4: The effect of compression ratio variation on maximum NOx levels

Figure 5 shows the effect of changing the engine speed on the NOx emitted. The maximum value of NOx concentrations is close to the stoichiometric ratio from the lean side (Ø= 0.93-0.96). The highest level of NOx was at 1500 rpm speed and an equivalence ratio (Ø = 0.95).

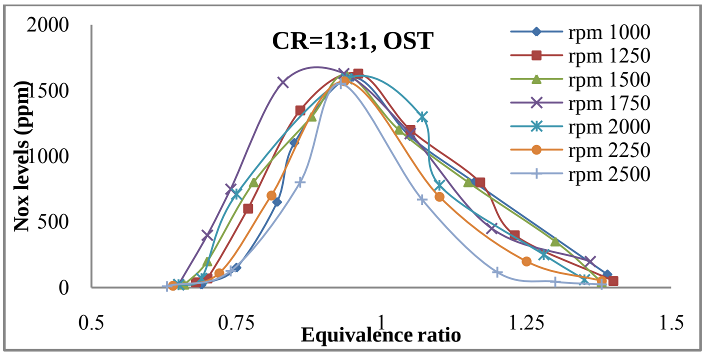

Figure 5: The effect of speed variation on NOx levels for wide range of equivalence ratios

The concentration obtained was 1600 ppm at an equivalent ratio of (Ø = 0.95) when the engine speed was 2500 rpm. The NOx concentrations increased with maximum speed to a certain speed depending on the equivalent ratio. At a rate of (Ø = 0.75), the highest NOx values are for the speed of 2000 rpm and the concentrations are lower when the speed was increased. For a rich ratio such as (Ø = 1.1), the concentration value is at 1500 rpm and less speed due to the lower temperature of the combustion chamber. At low speeds such as 1000 and 1250 rpm, NOx concentrations are low due to increased dilution and long burning time. The average velocity of (1500 and 1750 rpm) is considered to be suitable for increasing the NOx concentrations emitted to the room temperature and provides adequate time for oxidation. At high speeds (2250 and 2500 rpm), maximum NOx concentrations are limited to the time available to reaction and oxygen depletion because most of it is used to burn the fuel as well as decrease the volumetric efficiency of the engine by increasing speed.

Conclusions

Iraq is one of the richest countries in the world with natural gas, but to this day it imports its needs from this resource, which is wasted, from neighboring countries. Iraq loses a daily value of 15 million US dollars due to the burning of gas associated with crude oil extracted from the wells. In this study, the validity of the use of natural gas in motor vehicles was determined by measuring the pollution rates in NOx. Design variables were studied as compression ratio, and operational ones as the equivalence ratio, engine speed, and spark timing.

The equivalence ratio is the main factor affecting NOx concentrations in the exhaust gas. The NOx values are at the nearest correct chemical ratio from the weak side (Ø <1). These concentrations are lower in both the weak and rich sides. Retarded spark timing caused a significant decrease in NOx concentrations on the lean side and its maximum value was reduced also, however, on the rich side its effect was limited. The spark timing also increases the NOx concentration for all equivalence ratios in different degrees.

NOx values increase in the lean side by increasing the compression ratio while the maximum value of these concentrations decreases in this case. The NOx concentrations increase with the increase of speed of the engine from low to medium speeds and when the speed increases to a high speed, these concentrations decrease.

References

[1]. Al-Maamary, H. M. S., Kazem, H. A., Chaichan, M. T. (2016). Changing the energy profile of the GCC States: A review, *International Journal of Applied Engineering Research (IJAER)*, 11(3): 1980-1988.

[2]. Al-Maamary, H. M. S., Kazem, H. A., Chaichan, M. T. (2017). The impact of the oil price fluctuations on common renewable energies in GCC countries, *Renewable and Sustainable Energy Reviews*, 75: 989-1007.

[3]. Chaichan, M. T. (2015). The impact of engine operating variables on emitted PM and Pb for an SIE fueled with variable ethanol-Iraqi gasoline blends, *IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE)*, 12(6-1): 72-79.
[4]. Chaichan, M. T. (2016). GEM Ternary Blends utilization as an alternative to conventional Iraqi gasoline to suppress emitted sulfur and lead components to environment, *Al-Khwarizmi Journal*, 12(3): 38-51.
[5]. Al-Maamary, H. M. S., Kazem, H. A., Chaichan, M. T. (2017). Renewable energy and GCC States energy challenges in the 21st century: A review, *International Journal of Computation and Applied Sciences IJOCAAS*, 2(1): 11-18.
[6]. Al-Maamary, H. M. S., Kazem, H. A., Chaichan, M. T. (2017). Climate change: the game changer in the GCC region, *Renewable and Sustainable Energy Reviews*, 76: 555-576.
[7]. Chaichan, M. T. & Al-Asadi, K. A. H. (2015). Environmental Impact Assessment of traffic in Oman, *International Journal of Scientific & Engineering Research*, 6(7): 493-496.
[8]. Chaichan, M. T., Kazem, H. A. &Abid, T. A. (2018). Traffic and outdoor air pollution levels near highways in Baghdad, Iraq, *Environment, Development and Sustainability*, 20(2): 589-603.
[9]. Chaichan, M. T. (2018). GEM Ternary blends: Testing emitted NOx-smoke trading off when EGR is applied to the engine, *International Journal of Applied Science*, 13(7): 5014-5021.
[10]. Chaichan, M. T. (2018). Combustion and emission characteristics of E85 and diesel blend in conventional diesel engine operating in PPCI mode, *Thermal Science and Engineering progress*, 7: 45-53.
[11]. Chaichan, M. T., Salih, A. M., Abass, K. I. (2018). Magnetic field effects on methanol-diesel blends fueled CIE: Part A- engine performance, *World Wide Journal of Multidisciplinary Research and Development*, 4(7): 96-103.
[12]. Ekaab, N. S., Hamza, N. H., Chaichan, M. T. (2019). Performance and emitted pollutants assessment of diesel engine fuelled with Biokerosene, *Case Study of Thermal Engineering*, 13: 100381.
[13]. Chaichan, M. T., Ali, N. M. (2016). Experimental investigation of the effect of exhausts gas recirculation (EGR) on NOx-Smoke trade-off for SIE fueled with blends of gasoline/bioethanol, *Al-Rafidain Collage Journal*, 39: 388-404.
[14]. Chaichan, M. T., Abass, Q. A. (2016). Effect of cool and hot EGR on performance of multi-cylinder CIE fueled with blends of diesel and methanol, *Al-Nahrain Collage of Engineering Journal*, 19(1): 76-85.
[15]. Chaichan, M. T. (2016). Evaluation of emitted particulate matters emissions in multi-cylinder diesel engine fuelled with biodiesel, *American Journal of Mechanical Engineering*, 4(1): 1-6.
[16]. Salim, A. A.&Chaichan, M. T. (2004). Study of SIE performance fueled with hydrogen, *Sabha University Journal*, 6(3): 32-57.
[17]. Chaichan, M. T. (2008). Practical study of compression ratio, spark timing and equivalence ratio effects on SIE fueled with hydrogen. *Proceeding to Industrial Applications of Energy Systems, Sohar University*, Oman.
[18]. Chaichan, M. T.& Al Sheikh, S. A. (2001). Study of SIE performance fueled with methane, *Al-Jufra University Journal*, 1(1): 15-27.
[19]. Chaichan, M. T. (2007). Study of performance of SIE fueled with different kinds of hydrocarbon fuels, *Association of Arab Universities Journal of Engineering Science*, 14(1): 25-44.
[20]. Salim, A. A.&Chaichan, M. T. (2003). Study of SIE performance fueled with LPG, *Sabha University Journal*, 4(4): 67-82.
[21]. Salim, A. A. & Chaichan, M. T. (2002). Study of NOx and CO emissions for SIE fueled with LPG, *Sabha University Journal*, 1(1): 106- 125.
[22]. Chaichan, M. T. (2006). Study of performance of SIE fueled with Supplementary hydrogen to gasoline, *Baghdad Engineering Collage Journal*, 12(4): 983-996.
[23]. Chaichan, M. T. (2006). Study of NOx and CO emissions for SIE fueled with Supplementary methane to LPG, *The Iraqi Journal for Mechanical and Material Engineering*, 6(2): 85-97.

[24]. Chaichan, M. T. (2006). Study of NOx and CO emissions for SIE fueled with different kinds of hydrocarbon fuels, *Association of Arab Universities Journal of Engineering Science*, 13(2): 85-105.

[25]. Chaichan, M. T. & Abass, Q. A. (2010). Study of NOx emissions of SI engine fueled with different kinds of hydrocarbon fuels and hydrogen, *Al Khwarizmi Eng. Journal*, 6(2): 11-20.

[26]. Chaichan, M. T. & Abass, K. I. (2010). Experimental comparison of CO emissions emitted from single cylinder S I engine fueled with different kinds of hydrocarbon fuels and hydrogen, *Iraqi Journal for Mechanical and Material Eng.*, 10(3): 397-405.

[27]. Chaichan, M. T. (2011). Exhaust Analysis and Performance of a Single Cylinder Diesel Engine Run on Dual FuelsMode, *Baghdad Engineering Collage Journal*, 17(4): 873-885.

[28]. Chaichan, M. T. (2010). Practical measurements of laminar burning velocities for hydrogen-air mixtures using thermocouples, *Association of Arab Universities Journal of Engineering Science*, 17(2): 22-30.

[29]. Chaichan, M. T. (2013). Measurements of laminar burning velocities and Markstein length for LPG–hydrogen–air mixtures, *International Journal of Engineering Research and Development*, 9(3): 36-42.

[30]. Chaichan, M. T. (2013). The measurement of laminar burning velocities and Markstein numbers for hydrogen enriched natural gas, *International Journal of Mechanical Engineering & Technology (IJMET)*, 4(6): 110-121.

[31]. Chaichan, M. T. (2009). Study of performance of SIE fueled with Supplementary hydrogen to LPG, *Association of Arab Universities Journal of Engineering Science*, 16(1): 125-145.

[32]. Chaichan, M. T. (2010). Study of NOx and CO emissions for SIE fueled with Supplementary hydrogen to gasoline, *Baghdad Engineering Collage Journal*, 16(1): 4606-4617.

[33]. Chaichan, M. T. (2009). Study of NOx and CO emissions for SIE fueled with Supplementary hydrogen to LPG, *Association of Arab Universities Journal of Engineering Science*, 16(2): 32-47.

[34]. Chaichan, M. T. (2013). EGR effect on performance of a spark ignition engine fueled with blend of methanol-gasoline, *Wassit Journal of Engineering Science*, 1(2): 93-110.

[35]. Chaichan, M. T. (2014). Evaluation of the effect of cooled EGR on knock of SI engine fueled with alternative gaseous fuels, *Sulaimani Journal for Engineering Science*, 1(1): 7-15.

[36]. Chaichan, M. T. (2014). Exhaust gas recirculation (EGR) and injection timing effect on emitted emissions at idle period, *Al-Khwarizmi Engineering Journal*, 10(4): 33-44.

[37]. Chaichan, M. T. & Faris, S. S. (2015). Practical investigation of the environmental hazards of idle time and speed of compression ignition engine fueled with Iraqi diesel fuel, *International J for Mechanical and Civil Eng.*, 12(1): 29-34.

[38]. Chaichan, M. T., Abass, K. I. (2015). EGR and Injection Timing Variation Effects of an Engine Run in HCCI Mode Performance and Emitted Emissions, *International Journal of Engineering Trends and Technology (IJETT)*, 19(3): 120-130.

[39]. Khudhur, S. H., Saleh, A. M., Chaichan, M. T. (2015). The effect of variable valve timing on SIE performance and emissions, *International Journal of Scientific & Engineering Research*, 6(8): 173-179.

[40]. Chaichan, M. T. (2016). EGR effects on hydrogen engines performance and emissions, *International Journal of Scientific & Engineering Research*, 7(3): 80-90.

[41]. Chaichan, M. T., Maroon, O. K., Abass, K. I. (2016). The effect of diesel engine cold start period on the emitted emissions, *International Journal of Scientific & Engineering Research*, 7(3): 749-753.

[42]. Chaichan, M. T. (2016). Spark ignition engine performance fueled with hydrogen enriched liquefied petroleum gas (LPG), *Scholars Bulletin Journal*, 2(9): 537-546.

[43]. Chaichan, M. T. (2016). GEM Ternary Blends utilization as an alternative to conventional Iraqi gasoline to suppress emitted sulfur and lead components to environment, *Al-Khwarizmi Journal*, 12(3): 38-51.

[44]. Chaichan, M. T., Kadhum, J. A., Riza, K. S. (2016). Spark Ignition Engine Performance When Fueled with NG, LPG and Gasoline, *Saudi Journal of Engineering and Technology*, 1(3): 105-116.

[45]. Chaichan, M. T., Marhoon, O. K., Mohammed, B. A. (2016). The effect of spark ignition engine cold starting period on the emitted emissions, *Scientific and Eng. Reports*, 1(1): 1-8.
[46]. Chaichan, M. T., Abaas, K. I., Mohammed, B. A. (2017). Experimental Study of the Effect of fuel type on the Emitted Emissions from SIE at Idle Period, *Al-Khwarizmi Engineering Journal*, 13(1): 1-12.
[47]. Chaichan, M. T. (2018). Safety using of hydrogen as vehicle fuel: A review, *International Journal of Computation and Applied Sciences IJOCAAS*, 4(2): 316-323.
[48]. Chaichan, M. T.& Al-Sheikh, S. (2003). Study of, NOx and CO emissions for SIE fueled with methane.*Proceeding to International Conference for Energy and Environment, Brack*, Libya.
[49]. Saleh, A. M. and Chaichan, M. T. (2010). The effect of alcohol addition on the performance and emission of single cylinder spark ignition engine, *Proceeding to Najaf Technical collage international scientific conference, Najaf,* Iraq.
[50]. Chaichan, M. T. (2007). Study of performance of SIE fueled with Supplementary methane to LPG, *The Iraqi Journal for Mechanical and Material Engineering*, 7(4): 25-44.
[51]. Schurman, D., Craus, N. (1979).The influence of testing parameters on exhaust gas emissions, *SAE paper No. 796090*.
[52]. Shiomoto, A., Killy, W. F. (1978). Characteristics of lean misfire limit, *SAE paper No. 780235*.
[53]. Chaichan, M. T.&Saleh, A. M. (2010). Practical investigation of single cylinder SI Engine performance operated with various hydrocarbon fuels and hydrogen, *Al Mostaseria Journal for engineering and development*, 14(2): 183-197.
[54]. Chaichan, M. T. (2013). Experimental evaluation of the effect of some engine variables on emitted PM and Pb for single cylinder SIE, *Association of Arab Universities Journal of Engineering Science*, 2(20): 1-13.
[55]. Salih, A. M. & Chaichan, M. T. (2014). The effect of initial pressure and temperature upon the laminar burning velocity and flame stability for propane-air mixtures, *Global Advanced Research Journal of Engineering, Technology and Innovation*, 3(7): 154-201.
[56]. Alwaely, A. A., Al-qaralocy, H. N., Al-Asadi, K. A., Chaichan, M. T., Kazem, H. A., The environmental aftermath resulted from chemical bombardment of Halabja Territory for the period 1988-2014. *International Journal of Scientific & Engineering Research*, 6(9): 40-44.
[57]. Kazem, A. A., Chaichan, M. T.& Kazem, H. A. (2014). Effect of dust on photovoltaic utilization in Iraq: review article, *Renewable and Sustainable Energy Reviews*, 37: 734-749.
[58]. Chaichan, M. T., Kazem, H. A. (2018). Generating Electricity Using Photovoltaic Solar Plants in Iraq, *Springer, ISBN: 978-3-319-75030-9*.https://doi.org/10.1007/978-3-319-75031-6
[59]. Chaichan, M. T. (2018). Performance and emissions characteristics of CIE using hydrogen, biodiesel, and massive EGR, *International Journal of Hydrogen Energy*, 43: 5415-5435.
[60]. Al-Khishali, K. J., Saleh, A. M., Mohammed, H., Chaichan, M. T. (2015). Experimental and CFD Simulation for Iraqi Diesel Fuel Combustion, *1st International Babylon Conference, Babylon*, Iraq.
[61]. Chaichan, M. T., Kadhum, A. H., Al-Amiery, A. A. (2017). Novel technique for enhancement of diesel fuel: Impact of aqueous alumina nano-fluid on engine's performance and emissions, *Case Studies in Thermal Engineering*, 10: 611–620.
[62]. Chaichan, M. T. (2014). Combustion of dual fuel type natural gas/liquid diesel fuel in compression ignition engine, *Journal of Mechanical and Civil Engineering (IOSR JMCE)*, 11(6): 48-58.
[63]. Chaichan, M. T., Al-Zubaidi, D. S. M. (2014). A practical study of using hydrogen in dual – fuel compression ignition engine, *International Journal of Mechanical Engineering (IIJME)*, 2(11): 1-10.
[64]. Chaichan, M. T., Al-Zubaidi, D. S. M. (2014). Operational parameters influence on resulted noise of multi-cylinders engine runs on dual fuels mode, *Journal of Al-Rafidain University Collage for Science,* 35: 186-204.
[65]. Chaichan, M. T. (2015). The impact of engine operating variables on emitted PM and Pb for an SIE fueled with variable ethanol-Iraqi gasoline blends, *IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE)*, 12(6-1): 72-79.