Experimental Investigation of Performance and Exhaust Emissions of a Diesel Engine With Scrap Tires Rubber Oil Blended Diesel Fuel.

Nabel Kadum Abd-Ali[*]
[*]Materials Engineering Dep., College of Engineering, Al-Qadisiyha University.
nabelkadum@yahoo.com
Received 4 January 2016 Accepted 16 March 2016

Abstract

Using of scrap tires will result in recycle the waste of rubber products and solve the problem of increasing the prices of mineral fuel. Different blends of scrap tires rubber oil (STRO) and diesel fuel have been investigated experimentally using diesel engine for performance and emission products. A blend of 10, 20, 30, 40% and standard diesel fuel have been tested in the diesel engine and the results showed a good improvement in reducing the pollutants. One of the important problems facing the mixed with fuel oil is to increase the viscosity and decreasing volatility that lead to carbon deposition and ring sticking of these types of oils. When blended with diesel, (STRO) presented lower viscosity, improved volatility, better combustion and less carbon deposit. NO_x emission for the blend of 20% scrap tires rubber oil (STRO 20) was reduced by 40%. An increase in emission of hydrocarbon by 20% was found at full load. The emissions of carbon monoxide (CO) from scrap tires rubber oil and its blends were higher except in (STRO 20) blend that reduced by 15%. The brake thermal efficiency was spotted higher with standard fuel than scrap tire rubber oil and its blends. The present work showed that the 20% blending ratio is the optimum blending ratio for scrap tires rubber oil depending on experimental test results. Also, the current study introduce the waste of rubber products as a good alternative fuel blended with diesel fuel verify economical and environmental benefits.

Keywords: Scrap Tires, Rubber Oil, Blending Fuel, Mineral Diesel, Emission, Thermal Efficiency.

التحقيق التجريبي لأداء وانبعاثات العادم من محرك الديزل بوقود الديزل الممزوج بزيت مطاط الإطارات التالفة.

م.د. نبيل كاظم عبد علي
قسم هندسة المواد - كلية الهندسة- جامعة القادسية.

خلاصة.

تم إعادة تدوير الإطارات المطاطية التالفة لأيجاد وقود بديل بسبب زيادة أسعار الوقود المعدني .وقد تم تشكيل وفحص كفاءة الاداء لخلطات مختلفة من زيت مطاط الإطارات التالفة (STRO) مع وقود الديزل تجريبيا باستخدام محرك الديزل لقياس الأداء والانبعاثات. وقد تم اختبار مزيج زيت مطاط الاطارات التالفة بنسب تتراوح من (10%، 20%، 30%، 40%) مع وقود الديزل

القياسي وأظهرت النتائج تحسنا جيدا في الحد من الملوثات . حيث طرحت المشاكل الشائعة عند استخدام زيت ذو لزوجة عالية في محركات الإشعال مثل ضعف التذرية، ترسب الكربون والتصاق حلقات الضغط والتي تحدث نتيجة اختلاف لزوجة الزيوت المتنوعة. عند المزج مع وقود الديزل، قدم (STRO) خفض اللزوجة، تحسين التقلب، احتراق أفضل وأقل ترسب للكربون .تم تخفيض انبعاث أكاسيد النيتروجين على زيت مطاط الإطارات التالفة (STRO 20) مزيج بنسبة 40٪ .تم العثور على الزيادة في انبعاثات للهيدروكربون بنسبة 20٪ في حمولة كاملة .كانت انبعاثات أول أكسيد الكربون (CO) من مزيج وقود مطاط الإطارات التالفة أعلى إلا في حالة (STRO 20) مزيج حيث تم تخفيض بنسبة 15٪ . وبشكل قليل لوحظ ارتفاع الكفاءة الحرارية مع الديزل العادي للوقود المزيج مع زيت الاطارات التالفة .كذلك تقترح هذه الدراسة نسبة مزج 20٪ كنسبة مزج أمثل للوقود مع زيت مطاط الإطارات التالفة. تقدم الدراسة الحالية زيت مطاط الاطارات التالفة كوقود بديل مزيج مع وقود محركات الديزل لتحقيق منافع اقتصادية وبيئية.

Introduction

Recycling the waste generally solves two important issues for the humanity and the human beings in the earth planet. One of the hugest types of waste disposed every year by millions of tones is the car tires. Solving this issue is crucial mater economically and environmentally worldwide. In Iraq, although there are many tires factories such as Al-Diwaniyah Tires Factory and Babylon Tires factory in additional to many other rubber industries which increasing of the disposed tires, but there are no approaches to put real policies to recycle the wasted rubber material and tires and convert these materials into useful eco-friendly materials.

Tires mainly composed of different rubber compounds like vulcanized rubber, rubberized fabric, reinforcing textile cords, steel or fabric belts and steel-wire reinforcing beads. Different types of tires used nowadays natural and synthetic rubber such as natural rubber (*cis*-polyisoprene), styrene-butadiene rubber (SBR), *cis*-polybutadiene rubber (BR_{cis}). Another important components in tire manufacturing such as reinforcement agents, accelerator agents, anti ozinant agents, anti-oxidant agents, softening agents and other additives used in the tires[1].

Scrap rubber can be obtained from used tires by mechanical cutting into small chips. Many methods were investigated to eliminate this rubber waste like combustion, pyrolysis and hydrogenation. The use of scrap rubber for fuel is one of the best alternative processes for reusing rubber as natural gas and fuel oil costs increases. Pyrolysis, gasification, and liquefaction (PGL) represent a viable alternative methods for the disposal of scrap tires (waste tires). These technologies are currently used for the conversion of carbonaceous materials more extensively in Europe and Japan than in USA California, but may become more important as the supplies of natural fuels become depleted [2]. Pyrolysis techniques were used extensively in the literature to treat or recycle the waste tires. In the absence of oxygen in high temperature, scrap/waste tires can be decomposed via pyrolysis leading to the production of solid carbon residues, condensable fractions and gases[3]. The two parameters effect on the thermal decomposition of tires were tire composition and temperature. The pyrolysis of Williams and Besler [4] showed that, the major components of rubber tires: styrene–butadiene rubber (SBR), natural rubber (NR), and polybutadiene rubber (BR), the tire pyrolysis was done by a swept fixed bed reactor and nitrogen as carrier gas. Also, many authors such as Kaminsky et.al.[5] and Kawakami et.al. [6] had been used different types of reactors like fluidized bed reactors and rotary kilns, the work of both authors was done at higher temperatures than Williams and Besler [4] and they found that the liquid products yield was decreased and a higher gas formation was obtained.

In another studies, the authors obtained an active carbon from old tires using pyrolysis [7,8]. The co-processing of old tires with coal was the subject of many studies looking for a coal hydrogenation process enhancement [9–21]. The study of Gonzalez et al. [22] showed that the products of automobile tire waste pyrolysis in nitrogen atmosphere were approximately 37–40% char, 55% oil, and 4–11% gas.

The waste is an important source of renewable energy and considered as a potential to the world's energy. Being a source of green energy, these wastes make them a potential alternate for diesel fuel. There are many waste oils identified by the researchers, which could be used as engine fuels. The use of biodiesel provide reductions in particulate matter, carbon monoxide and unburned hydrocarbon emissions. The studies on the substitution of diesel fuel by 20% blend showed a decreases in the emission of particulate matter on average by 25% for engines and meeting the standard for the pollutant emissions[23].

The previous studies showed that, the brake thermal efficiency outcomes of biodiesel-diesel fuel blending include slight elevations [24-33], a slight reduction [34,35] and unfounded variations [36-39]. The reasons for these results may be attributed to the reduction in friction power due to biodiesel lubricity [27,40], present of oxygen in biodiesel [27,31], increase in combustion efficiency [24,25,30], improving the combustion characteristics [41] and variations in fuel vaporization and ignition processes [29].

Some authors identified a balance between the increased thermal efficiency and the fuel's reduced heating value which lead to change in the specific fuel consumption (sfc) affected by the biodiesel blend. The results indicated that the minimum (sfc) is achieved with diesel fuel of 10% [24,29,32,40], 15% [34] or 20% blending with biodiesel fuel [25,27,31]. In 2012, G. Kasiraman et. al [42], studied the performance, emission and combustion characteristics at various loads on the engine at a constant speed of 1500 rpm they found that the blends of 30% camphor oil shows good performance with diesel fuel operation with respect to brake thermal efficiency and heat release rate at full load. Also results showed experimentally that, The brake thermal efficiency of camphor oil blend 30 is 29.1% compared to base diesel engine brake thermal efficiency of 30.14%. The camphor oil blend 30 emits 1040 ppm of nitric oxide, while diesel emits 1068 ppm. The neat cashew nut shell oil emits 983 ppm of nitric oxide [42].

To the best of our knowledge, no previous research has been conducted on the performance and emissions of scrap tires rubber oil (STRO) produced from tires of Al-Diwaniya tire factory blended with diesel fuel. So, the present study will investigate the performance, emission and combustion characteristics of a diesel engine fueled with scrap rubber oil (STRO) and its diesel blends compared to those of standard diesel and introduce this material as a good alternative material verifying economical and environmental benefits result from using scraped material.

Experimental Tests

Electrical Laboratory furnaces under vacuum condition including spiral condenser were used to extract oil locally in (450-500 ^{0}C) from truck tire cross-play reinforced by nylon fabric that manufactured by Al-Diwaniyah Tires Factory. These tires composed of natural and synthetic rubber (NR, SBR, BR_{cis}), reinforcement agent (carbon black), mineral plasticizer (aromatic) oil, vulcanization agent (sulfur), zinc oxide, stearic acid, retarder agent, accelerator agent, anti- oxidant agent, anti- ozonant agent, activators agent …etc. according to Italian Pirelli Co. recipes.

The engine was operated on standard diesel fuel first and then on scrap rubber oil-diesel fuel blends with 10%, 20%, 30%, 40% scrap tires rubber oil and neat scrap rubber oil. Four blending fuels were studied and employed in the experiments in addition to standard diesel fuel, and pure scrap rubber oil. The blends were 90% diesel fuel and 10% scrap tire rubber oil (STRO 10), 80% diesel fuel and 20% scrap tire rubber oil (STRO 20), 70% diesel fuel and 30% scrap tire rubber oil (STRO 30), 60% diesel fuel and 40% scrap tire rubber oil (STRO 40). It can be seen that scrap tire rubber oil blends easily with the standard fuel and get the economic homogeneous mix for long periods. Also, such substance can be obtained from the local markets with good specifications. The properties of the diesel fuel was listed in **table (1)**.

Flash point which used in shipping and safety regulations to define flammable and combustible materials was measured by SYD-3536 COC Flash Point Apparatus (Shanghai Shenxian Instrument Co.) according to ASTM D93. The carbonaceous residue is reduced to an ash by heating in a muffle furnace at 775°C, according to ASTM D482. Moisture was measured according to standard specification for diesel fuel oils ASTM D975 and ASTM 396 for calculating fixed carbon. Gross Calorific Value determined by Calorimeter Vessel according to ASTM D2015. Accurate determination of the density; relative density (specific gravity) was done according to ASTM D1298.

Also, the kinematic viscosity of liquid petroleum products was calculated by measuring the period of flow the fixed volume of liquid at a specific temperature by SYD-265C Petroleum Products Kinematic Viscosity Tester (Shanghai Shenxian Instrument Co.), according to ASTM D445. The heat of combustion as determined by ASTM D240 is designated as one of the chemical and physical requirements; The mass heat of combustion, the heat of combustion per unit mass of fuel, is a critical property of fuels, where a knowledge of this value is essential when considering the thermal efficiency of equipment for producing either power or heat. Finally, The elemental analyzer (EURO EA) used to identify some elements such as carbon, sulfur, hydrogen and nitrogen in material that used during this study and according to ASTM D5291 and ASTM D5453. **Table (2)** include all these data.

The data obtained from Gas Chromatograph GC-2010 (SHIMADZU Co.) was used to assess the simulated distillation curves. gas chromatograph was used to carried out identification of compounds.

The tests were first conducted with diesel fuel at full-load conditions and the engine speed was changed between 1200 and 2800 rpm at the standard injection pressure of 171 bar with intervals of 200 rpm to obtain the base data of the engine and all these tests were performed under steady state conditions and repeated three times to find the average. The engine was operated after each fuel test, for at least 30 min to consume the fuel which was left in the fuel system from the previous test. The experimental values of the engine performance parameters such as brake specific energy consumption, brake thermal efficiency, exhaust gas temperature, NO_x emission, unburned fuel emission, carbon monoxide emission and carbon dioxide emission were determined and compared in graphics.

Engine Specification

Tests were performed using Perkins (1006/TAG2) generator. The main specifications of the test engine were shown in **table (3)**

.

IMR1400 Exhaust Gas Analyzer Apparatus

IMR1400 exhaust gas analyzer shown in **figure (1),** was used to measured HC, CO and NO_x emissions in ppm. The IMR1400 unit measures ambient or room temperature, gas temperature, draft pressure, smoke spot O_2 and CO. All further values, as CO_2, air free, excess air, efficiency and losses are calculated. Also this unit is a comfortable, easy to use flue gas analyzer in robust aluminum case. All accessories needed for measuring are situated inside the case, so that an immediately readiness is guaranteed. To reach the highest accuracy , the analyzer should have an ambient temperature between 10 and 40 ºC [43].

Tested Parameters

The specific fuel consumption (*sfc*) is a function of brake power (P_b) and fuel mass flow rate (m_f) [44]:

$$sfc = \frac{\dot{m}_f}{P_b} \quad ...(1)$$

The engine brake thermal efficiency (η) include some of parameters for comparisons of different fuels, taking into account the effect of differences in the exergy values [45]:

$$\eta = \frac{P_b}{\dot{m}_f \, ex_f} \quad ...(2)$$

Where (ex_f) is the specific flow exergy of the fuel. Also the specific volumetric fuel consumption is possible to express as[44,45]:

$$svfc = \frac{1}{\eta \rho_f \, ex_f} \quad ...(3)$$

Where (ρ_f) is the fuel density.

Results and Discussion

In this paper, the performance and emission characteristics were performed for standard diesel fuel, neat scrap rubber oil and the four blending diesel fuel.

Performance Analysis

The brake specific energy consumption (BSEC) and brake thermal efficiency for standard diesel fuel, neat scrap rubber oil , and its blend with diesel fuel for different blends of 10, 20, 30, and 40% were calculated for the present engine of the specifications showed in table (2). The results were analyzed and showed graphically in **figures (2)** and **(3)**. **Figure (2)** shows that, the lower heating value of scrap tire rubber oil made a largely Differences in BSEC. The resulting increase in required mass fuel flow was needed to obtain similar fuel energy input. At all loads, the brake specific energy consumption of scrap rubber oil blends was 7–20% greater than that of standard fuel and these results may be related to the differences in heating and density between scrap rubber oil and standard fuel. Also, brake thermal efficiency was 2-16% lower for scrap rubber oil and other blends. Brake thermal efficiency decreases with increasing percentage of scrap rubber oil, **figure (3**). This may be related to the needy combustion characteristics of these blends due to their high viscosity and low volatility.

Exhaust Gas Temperature.

Figure (4) shows the temperature of exhaust gas variation with respect to the load. The reason of increasing the temperature of exhaust gas with increasing percentage of scrap rubber oil in the blends may be related to the turnout of constituents with higher effervescence points in scrap rubber oil than in standard fuel. Not adequately evaporated constituents having higher effervescence points were during the main combustion stage and continued to the late combustion as a result of the heavy constituents. The lower thermal efficiency was resulted in a higher temperature of exhaust gas of 2-15%.

Analysis of Emission

Emission of Nitrogen Oxides (NO_x)

Figure (5) showed the divergence of NO_x emission for different blends with respect to the load. The higher combustion temperature increase NO_x emissions with the engine load. This proves that the temperature of combustion is the most effective factor for the emissions of NO_x in the cylinder of engine. From **figure (5),** it can be seen that the NO_x emissions from scrap tire rubber oil and its blends are lower than those of standard fuel. About 25-40% reduction of the NO_x emission was reported for all loads. This is may be due to the lower value of heating of scrap rubber oil. Emission of NO_x is the most hurtful gaseous emissions.

Unburned Emission

Figure (6) showed that, the unburned fuel emission for scrap rubber oil and its blends were higher than those of diesel fuel except (STRO 20) blend where lower by 10 % and 30% compared with the standard diesel and neat scrap rubber oil at full load respectively. The emissions of hydrocarbon fuels may be greatly affected the physical properties of the fuel such as viscosity and density. And cause an increase certain ratios of the fuel blends increase the proportion of the production of hydrocarbons (HC), which affects the quality of the fuel spray. Where it is increasing the size of the mixture of fuel droplets, which affect the performance of the combustion process and thus the performance of the engine. We can note that the fuel mixture ratios of 10% and 20% may have given the best results in comparison with the highest ratios in addition to the standard were decreased 7-14% lower than the standard at full load respectively. These results were attributed to the sensitivity of the change in a fuel viscosity.

Carbon Monoxide Emission

The results of mixing diesel fuel with low rates of scrap tire rubber oil give better results compared with the high mixing ratios, as well as in comparison with the standard fuel. **Figure (7)** shows a reduction in emissions of carbon monoxide by 20% and 50% of the mixing ratios of 10% and 20% respectively. While causing high mixing of the scrap rubber fuel oil with the standard rates of a significant increase in the production of this gas. Also, high mixing ratios of scrap tire rubber oil caused a decline in the quality and performance of the engine as has been discussed previously.

Carbon Dioxide Emission

The CO_2 emission as expected, increases with an load increasing. **Figure (8)** compares the CO_2 emissions of various scrap rubber diesel blends. The emissions of CO_2 of diesel fuel were the higher compared with the other. The carbon content in scrap rubber oil diesel blends at the similar load in the same volume was lower; so, the emissions of CO_2 from scrap rubber oil and these blends were lower than of standard diesel. Because of the incomplete combustion The plants can absorb unwanted emissions of CO_2 ensures nappy on a balanced its level in the atmosphere.

Conclusions

The engine power output and fuel consumption of the engine for the blends compared with those of standard diesel were almost not different when engine work with lower scrap rubber blends of oil diesel. The present experimental tests showed a comparison for the engine run on scrap rubber blends of oil diesel with that of standard. At all loads, BSEC of scrap rubber oil blends was 7–20% greater than the standard. Additionally, brake thermal efficiency was 2-16% lower for scrap tires rubber oil and its blends, where it decreases with increasing of scrap rubber oil. So, the differences in heating value and density between scrap rubber oil and standard fuel may be caused these results.

The lower thermal efficiency was resulted in a higher exhaust temperature of gas of 2-15%. Due to the lower heating value of scrap rubber oil, about 3-40% reduction of the NO_x emission was reported for all loads. The unburned fuel emission for scrap rubber oil and its blends were higher than those of standard fuel except (STRO 20) blend where lower by 10 % and 30% compared with the standard diesel and neat scrap rubber oil at full load respectively. Also carbon monoxide emission (CO) at full load were 20 % and 50% lower than that of standard diesel and neat scrap rubber oil respectively. The CO_2 emission increases with load increasing and this may be related to the incomplete combustion. It can maintain the level of CO_2 through photosynthesis performed by plant, where the level of this gas kept in balance in the atmosphere. Finally, the results extracted from the current study considered the scrape tire rubber oil verify economical and environmental aims represented by disposal of waste material needs several decades to biodegradable and convert it to useful material.

Acknowledgement

I would like to express my deep appreciation and sincere thanks to Al-Diwaniyah and Babylon Tires Factories, Al-Qadissiya University, specially Laboratories of Engineering College, Babylon University- specially Laboratories of Sciences College and Basic Education for Girls College.

References:

[1] A.M. Mastral, R. Murillo, M.S. Callen, T. Garcia, Optimisation of scrap automotive tyres recycling into valuable liquid fuels, Resources and Conservation and Recycling 29 (2000) 263–272.

[2] Mahmood M. Barbooti,Thamer J. Mohameda, Alaa A. Hussain, Falak O. Abasa, Optimization of pyrolysis conditions of scrap tires under inert gas atmosphere, J. Anal. Appl. Pyrolysis 72 (2004) 165–170. doi:10.1016/j.jaap.2004.05.001.

[3] Diez, C., Martinez, O., Calvo, L.F., Cara, J., Maran, A., 2004. Pyrolysis of tire. Influence of the final temperature of the process on emissions and the calorific value of the products recovered. Waste Management 24, 463–469.

[4] Williams, P.T., Besler, S., 1995. Pyrolysis-thermo gravimetric analysis of tires and components. Fuel 74, 1277–1283.

[5] Kaminsky W, Sinn H. Thermal Conversion of Solid Wastes and Biomass, American Chemical Society Symposium Series 130. Washington DC: ACS Publishers, 1980.

[6] Kawakami S, Inone K, Tanaka H, Sakai T. American Chemical Society Symposium Series 130.Washington DC: ACS Publishers, 1980.

[7] Teng H, Serio M, Wo´ jtowicz MA, Bassilakis R, Solomon PR. Ind Eng Chem Res 1995;34:3102–11.

[8] Merchant AA, Petrich MA. AIChE J 1993;39(8):1370–6.

[9] Farcasiu M,Smith CM.Am Chem Soc Fuel Chem Div Preprints 1992;37(1):472–9.

[10] Farcasiu M. Chemtech 1993;23(1):22–4.

[11] Liu Z, Zondlo JW, Dadyburjor DB. Energy Fuels 1994;8(3):607–12.

[12] Mastral AM, Murillo R, Pe´rez-Surio MJ, Calle´n MS. Energy Fuels 1996;10(4):941–7.

[13] Tang Y, Curtis CW. Fuel Processing Technol 1996;46(3):195–215.

[14] Tang Y,Curtis CW.Am Chem Soc Div Fuel Chem Preprints 1996;41(3):1057–61

[15] Orr EC, Shi Y, Shao L, Liang J, Ding W, Anderson LL, Eyring EM. Fuel Processing Technol. 1996;49(1:3):233–46.

[16] Orr EC, Shi Y, Ji Q, Shao L, Villanueva M, Eyring EM. Energy Fuels 1996;10(3):573–8.

[17] Mastral AM, Murillo R, Calle´n MS, Pe´rez-Surio MJ, Mayoral MC. Energy Fuels 1997;11(3):676– 80.

[18] Anderson LL, Calle´n MS, Ding W, Liang J, Mastral AM, Mayoral MC, Murillo R. Ind Eng Chem Res 1997;36:4763–7.

[19] Liu Z, Dadyburjor DB. Energy Fuels 1995;9:673.

[20] Mastral AM, Murillo R, Mayoral MC, Calle´n MS. Energy Fuels 1997;11:813–8.

[21] Mastral AM, Murillo R, USA Patent 5960 123, March 1997.

[22] Gonzalez, J.F., Jose, M.E., Jose, L.C., Juan, J.R., 2001. Pyrolysis of automobile tire waste. Influence of operating variables and kinetics study. Journal of Analytical and Applied Pyrolysis, 58–59, 667–683.

[23] McCormick RL, Tennant CJ, Hayes RR, Black S, Ireland J, McDaniel T, Regulated emissions from biodiesel tested in heavy-duty engines meeting, 2004 emission standards. Society of Automotive Engineers; 2005. SAE Paper 2005-01-2200.

[24] Ali Y, Hanna MA, Leviticus LI. Emissions and power characteristics of diesel engines on methyl soyate and diesel fuel blends. Bioresource Technology 1995;52(2):185-95.

[25] Agarwal AK, Das LM. Biodiesel development and characterization for use as a fuel in compression ignition engines. Transactions of the ASME 2001;123:440-7.

[26] Al-Widyan MI, Tashtoush G, Abu-Qudais M. Utilization of ethyl ester of waste vegetable oils as fuel in diesel engines. Fuel Processing Technology 2001;76(2):91-103.

[27] Raheman H, Phadatare AG. Diesel engine emissions and performance fromblends of karanja methyl ester and diesel. Biomass and Bioenergy 2004;27(4):393-7.

[28] Ramadhas AS, Muraleedharan C, Jayaraj S. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renewable Energy 2005;30(12) ,1789e800.

[29] Labeckas G, Slavinskas S., The effect of rapeseed oil methyl ester on direct injection diesel engine performance and exhaust emissions, Energy Conversion and Management 2006;47(13):1954-67.

[30] Lin YC, Lee WJ, Hou HC. PAH, emissions and energy efficiency of palm-biodiesel blends fueled on diesel generator. Atmospheric Environment 2006;40(21):3930-40.

[31] Raheman H, Ghadge SV., Performance of diesel engine with biodiesel at varying compression ratio and ignition timing. Fuel 2008;87(12):2659-66.

[32] Bueno AV, Velásquez JA, Milanez LF. Effect of soybean oil ethyl ester/diesel fuel blend on engine efficiency. International Journal of Vehicle Design 2009;50(1): 229-47.

[33] Godiganurb S, Murthy CHS, Reddy RP. 6BTA 5.9 G2eG1 Cummins engine performance and emission tests using methyl ester mahua (Madhuca indica)oil/diesel blends. Renewable Energy 2009;34(10):2172-7.

[34] Lin YC, Lee WJ, Wu TS, Wang CT. Comparison of PAH and regulated harmful matter emissions from biodiesel blends and paraffinic fuel blends on engine accumulated mileage test. Fuel 2006;85(17):2516-23.

[35] Baiju B, Naik MK, Das LM. A comparative evaluation of compression ignition engine characteristics using methyl and ethyl esters of Karanja oil. Renewable Energy 2009;34(6) ,1616-21.

[36] Canakci M. Performance and emissions characteristics of biodiesel from soybean oil. Proceedings of the institution of mechanical engineers, part D.Journal of Automobile Engineering 2005;219(7):915-22.

[37] Rakopoulos CD, Antonopoulos KA, Rakopoulos DC, Hountalas DT, Giakoumis EG. Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or biodiesels of various origins. Energy Conversion and Management, 2006;47(18):3272-87.

[38] Rakopoulos CD, Rakopoulos DC, Hountalas DT, Giakoumis EG, Andritsakis EC. Performance and emissions of bus engine using blends of diesel fuel with biodiesel of sunflower or cottonseed oils derived from Greek feedstock. Fuel 2008;87(2):147-57.

[39] Tsolakis A, Megaritis A, Wyszynski ML, Theinnoi K. Engine performance and emissions of a diesel engine operating on diesel-RME (rapeseed methyl ester) blends with EGR (exhaust gas recirculation). Energy 2007;32(11):2072-80.

[40] Ramadhas AS, Muraleedharan C, Jayaraj S. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renewable Energy 2005;30(12): 1789-800.

[41] Kaplan C, Arslan R, Sürmen A. Performance characteristics of sunflower methyl esters as biodiesel. Energy Sources 2006;28(8):751-5.

[42] G. Kasiraman, B. Nagalingam, M. Balakrishnan, Performance, emission and combustion improvements in a direct injection diesel engine using cashew nut shell oil as fuel with camphor oil blending, Energy 47 (2012) 116-124.
[43] Exhaust Gas Analyzer User's Manual.

[44] Andre Valente Bueno, José Antonio Velásquez, Luiz Fernando Milanez, Heat release and engine performance effects of soybean oil ethyl ester blending into diesel fuel, Energy 36 (2011) 3907e3916, Doi:10.1016/j.energy.2010.07.030.

[45] Hindren A. Saber, Ramzi R. Ibraheem Al-Barwari, Ziyad J. Talabany, Effect of Ambient Air Temperature on Specific Fuel Consumption of Naturally Aspirated Diesel Engine, Journal of Science and Engineering Vol. 1 (1), 2013, 1-7.

Table (1): Standard Specifications of Diesel Oil.

Properties	Diesel Fuel
Flash point	50C
Specific gravity	0.84
Carbon residue	0.15 or less
Cetane value	50 up
Colour	4 or less
Pour point	10C
Calorific value kcal/kg	10170
Sulpher %	1.2 or less
Kinematics viscosity cs	2.7
Distillation point	350C

Table (2): Analysis of Scrap Tires Rubber Oil.

Properties	Scrap Rubber Oil
Flash Point, Closed Cup, ^{0}C,	28
Ash, % mass	3.15
Moisture	1.20
Fixed carbon	24.25
Gross calorific value (GCV),MJ kgK^{-1}	40.27
Specific gravity, g.cm^{-3}	0.86
Viscosity, CSt (at 40 ^{0}C)	3.28
Elemental Analysis (N, H, C)	
Nitrogen, (ppm)	0.67
Hydrogen, (ppm)	9.86
Carbon, (ppm)	82.91
Sulfur, (ppm)	0.92

Table (3): The Main Specifications of the Test Engine.

Make	**Superstar**
Cylinder number	6-Vertical in Line Cylinders
Type	Direct Injection
Bore/stroke	94.2 mm/125 mm
Stroke	Four Stroke
Compression ratio	18:1
Cooling system	Water Cooled
generating set model -PL150	150 KVA prime power, 16.5 KVA standby power

a)

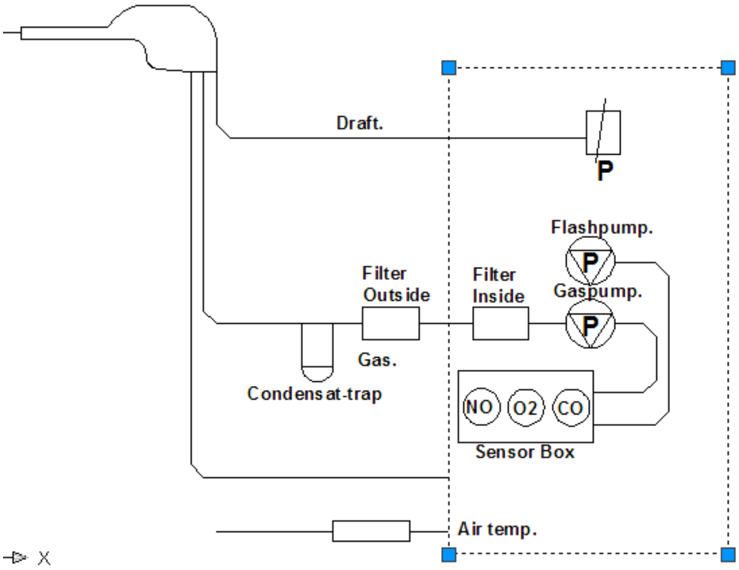

b)


Figure (1): (a) The flue gas analyzer unit (IMR 1400). (b) The gas flow through the flue gas analyzer unit (IMR 1400),

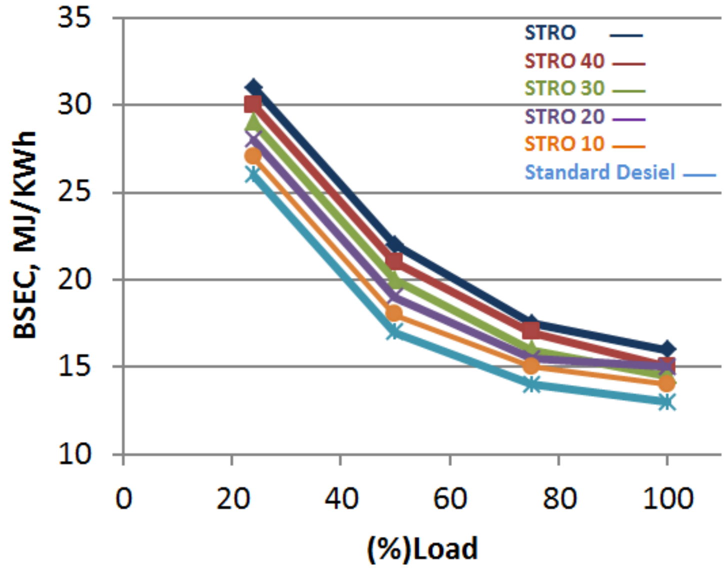


Figure (2): Consumption of the Brake Specific Energy.

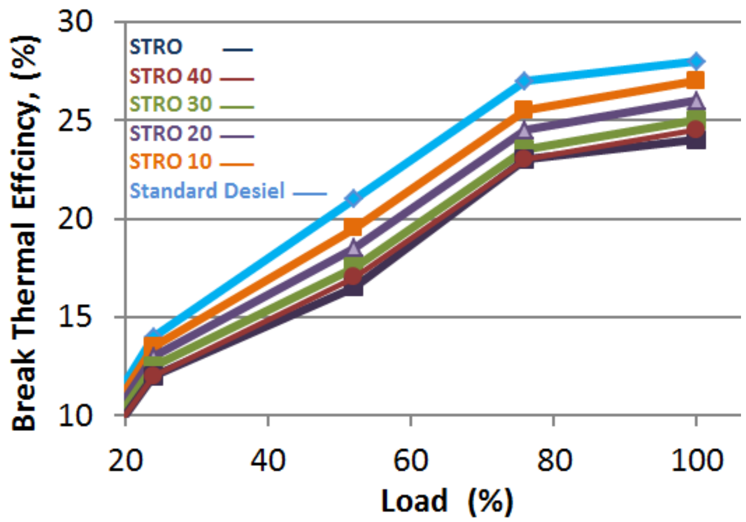


Figure (3): Brake Thermal Efficiency.

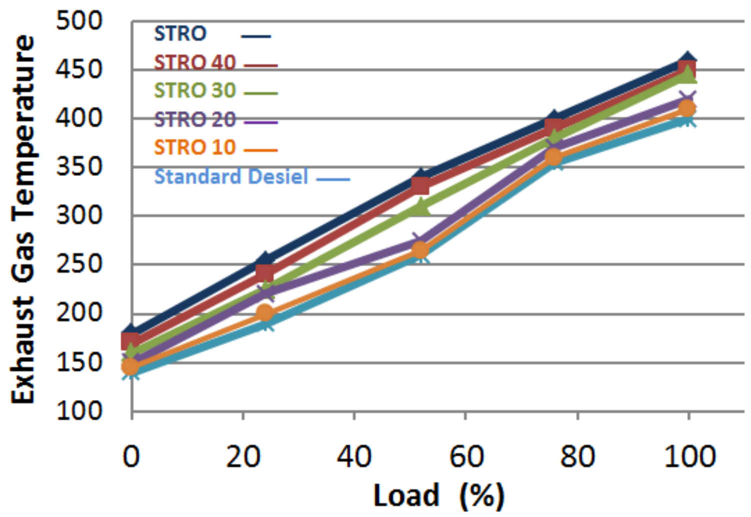


Figure (4): Exhaust Gas Temperature.

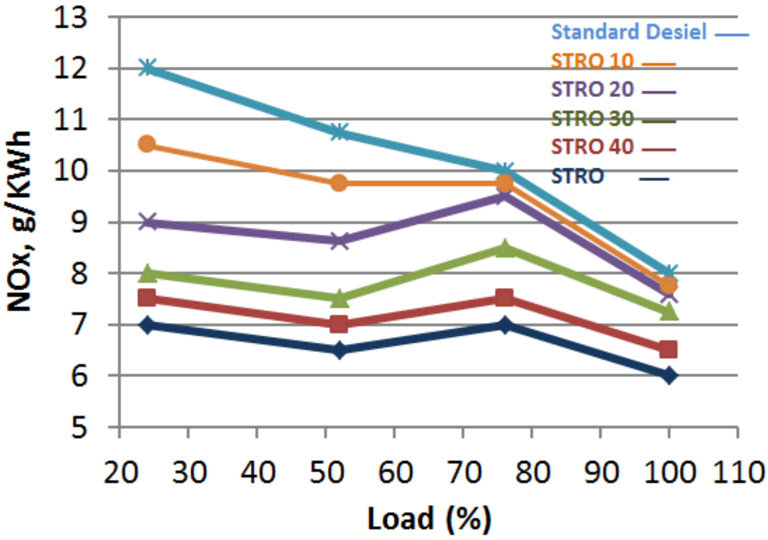


Figure (5) : The Variation of NO_x Emission.

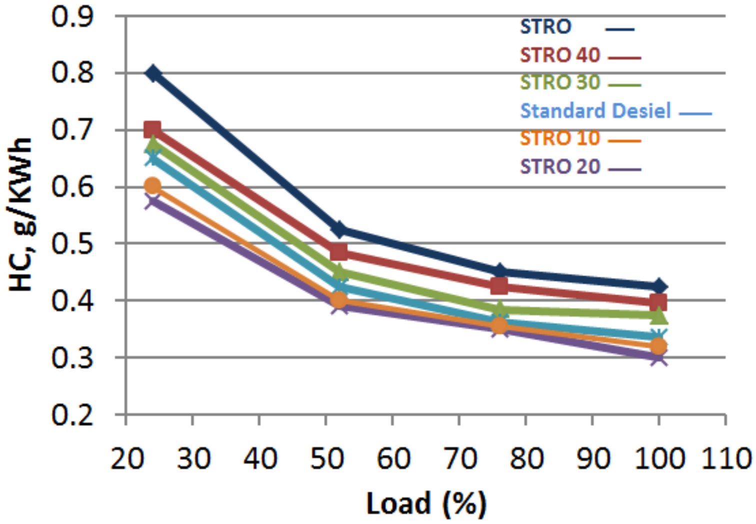


Figure (6): Hydrocarbons (Unburned Fuel) Emission.

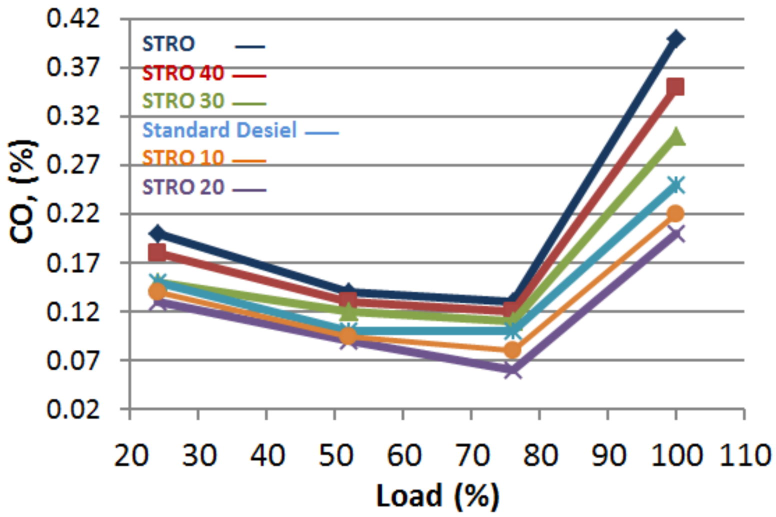


Figure (7): Carbon Monoxide Emission.

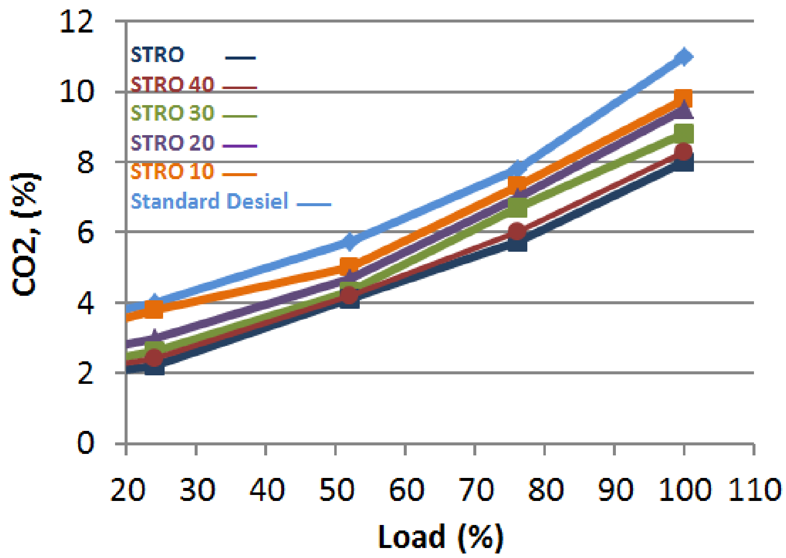


Figure (8): Carbon Dioxide Emission.