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EXPERIMENTAL INVESTIGATION ON AN EXHAUST EMISSION CHARACTERISTICS OF A COMPRESSION IGNITION ENGINE FUELED WITH DIESEL-WATER EMULSION

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ABSTRACT

One of the main sources of global air pollution is the undesirable gas emissions from diesel engines, as well as the accompanied particulate matters (PM). Consequently, the reduction of their amount and quality is highly recommended for clean environment. The present work includes an attempt to use diesel-water emulsion as a fuel on compression ignition (CI) engine emissions and to investigate its effect on these hurtful discharges. For this reason, tests are carried out on a single cylinder, 4-stroke CI engine with steady speed (1500 rpm) and different loads (0-100 %) operated with various proportions of diesel-water emulsions and compared it to the diesel fuel. Four samples of diesel-water emulsions are prepared at ratios of (5, 10, 15 and 20 %) by water volume in diesel and with help of Tween 20 and Oleic Acid as a surfactant to maintain its stability for long periods of time. Gas emissions of the engine are recorded for CO_2, CO, HC, and NO_X using an exhaust gas analyzer and smoke opacity using a device of smoke meter. Results reveal that the diesel-water emulsion significantly decreases the NO_X emissions and smoke opacity. The highest reduction ratio for NO_X and smoke opacity are found in case of fuel emulsion DW20, with values of 32.5 % and 39 % respectively, in comparison with that of diesel fuel.

Keywords: CI engine, diesel-water emulsion, NO_X emission, smoke opacity

التحقيق التجريبي لخصائص انبعاثات عادم محرك الاشتعال الانضغاطي (CI) يعمل بمستحلب الديزل-الماء

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الخلاصة

ان أحد المصادر الرئيسية لتلوث الهواء العالمي هو انبعاثات الغازات غير المرغوب فيها المنبعثة من محركات الديزل، أضافة الى المواد الدقائقية (PM). ويترتب على ذلك ضرورة تقليل كميتها ونوعيتها من اجل بيئة نظيفة. يتضمن البحث الحالي محاولة لتجربة استخدام مستحلب الديزل-الماء كوقود على انبعاثات محرك الاشتعال الانضغاطي (CI) وللتحقق من تأثيره على هذه الانبعاثات المؤذية. لهذا الغرض يتم إجراء الاختبارات على محرك CI رباعي الأشواط ذي أسطوانة واحدة وسرعة ثابتة (1500 دورة في الدقيقة) وأحمال مختلفة (0-100 ٪) تعمل بنسب مختلفة من مستحلبات الديزل-الماء

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ومقارنتها بوقود الديزل. تم تحضير أربع عينات من مستحلبات الديزل-الماء بنسب (5 ، 10 ، 15 و20 ٪) من حجم الماء في الديزل وبمساعدة Tween 20 و Oleic Acid كعامل فاعل بالسطح للحفاظ على استقراره لفترات طويلة من الزمن. تم تسجيل انبعاثات الغازات من المحرك بالنسبة لثاني أكسيد الكاربون CO_2 وأول أكسيد الكربون CO والهيدروكربونات HC وأكاسيد النيتروجين NO_X باستخدام محلل غازات العادم وعتامة الدخان باستخدام جهاز مقياس الدخان. كشفت النتائج أن استخدام مستحلب الديزل-الماء يقلل بشكل كبير من انبعاثات أكاسيد النيتروجين وعتامة الدخان. تم العثور على أن أعلى نسبة تخفيض لأكاسيد النيتروجين وعتامة الدخان تحصل عند استخدام مستحلب الوقود DW20 ، بمقدار 32.5 ٪ و 39 ٪ على التوالي، مقارنة مع وقود الديزل.

NOMENCLTURE

Latin Symbols	Description
BSFC	brake specific fuel consumption (kg/kW.sec)
CI	compression ignition
CO	carbon monoxide (% Vol)
CO_2	carbon dioxide (% Vol)
DI	direct injection
DW	diesel-water emulsion
HC	unburnt hydrocarbons (ppm)
HLB	hydrophilic – lipophilic balance
NO_X	nitrogen oxides (ppm)
PAH	polycyclic aromatic hydrocarbon
PM	particulate meters
ppm	parts per million

INTRODUCTION

The kinetic energy of the fuel obtained from various engine types was originated from its potential chemical energy. Diesel engines find wide applications in power generation sector in Iraq as well as in transportation, agriculture and industrial sector Hegde et al. (2016). No wonder for that, for it has sound economical consumption of fuel as well as having greater power and higher efficiency compared with that of gasoline engine Seifi et al. (2016). Unfortunately, some harmful emissions of environmentally unrecommended gases were emitted, among them were; NO_X, CO, CO_2, HC and smoke, which were formed through the combustion process Jiaqiang et al. (2016). The emissions of NO_X and smoke were responsible for the main sources of air pollution, and can cause serious harms to humans, animals, plants and environment Mondal and Mandal (2019). A helpful alternative for these unwanted emissions is highly needed to improve the performance and for mitigation purposes by the environmentalists. The emulsions of diesel-water can be considered as an alternative to reduce the emission of NO_X and smoke simultaneously, provided that there will be no significant modifications to the engine Ithnin et al. (2014). The provided explanation is based on the fact that steam generated from water will absorb the produced combustion heats, which consequently decrease the flame temperature accompanied by NO_X and smoke emissions reduction Şahin et al. (2014), Marchitto et al. (2018). Many articles appeared in the literature that deals with the mixing the basic diesel fuel with biodiesel, alcohol, gasoline, water, or other materials. Paul et al. (2017), Pongamia piñata methyl esters (PPME) at proportion of 50 % and 5 - 20 % ethanol blend was used in a diesel engine to comparative and evaluate the engine performance. Results showed that a blend of 50 % PPME, 15 % ethanol and 35 % diesel fuel has two major effects on the engine performance through the reduction of fuel consumption as well as increasing its thermal efficiency. Kannan and Anand (2011), a series of experiments were conducted using diesel, biodiesel and biodiesel – diesel – ethanol (diestrol) water micro emulsion as a fuels to evaluate the performance, emission and combustion characteristics of the diesel engine at different loads and constant speed of 1500 rpm. It was found that the brake specific fuel consumption (BSFC) for biodiesel and micro emulsion fuels were higher than that of diesel alone, and the emission characteristics (CO, CO_2, HC and NO_X) were lower than that those of diesel fuel at all loads. Also found the heat release rate was higher compared with the biodiesel and diesel fuels for all loads. Lin et al. (2011), in another experiment, polycyclic aromatic hydrocarbon (PAHs) as well as PM were emitted from n-butanol combustion in blend of diesel fuel–butanol-water emulsion. It was found that increasing the proportion of n-butanol reduced the PM emissions and PAHs, but at the same time increased the CO emissions and fuel consumption. Salih (2017), the effect of water proportion in the diesel emulsion on diesel engine was studied, reveals that 20-30 % of the water volume improves the engine performance and reduces the emissions. Alahmer et al. (2010), a series of experiments was carried on a diesel engine to evaluate the performance and emissions at speed range from 1000 to 3000 rpm, using diesel with 5 to 30 % water emulsion blends. The results indicated a decrease NO_X emissions and significant improvement in fuel consumption and thermal efficiency. Ochoterena et al. (2010), Combustion properties and spray behavior of diesel-water emulsion was studied and concluded that such emulsion lead to a lower soot formation as well as slight ignition delay. Dubey and Saxena (2016), when a set of 10-30 % emulsions were used; it improved the performance and significantly reduces the emissions of NO_X and PM. Scarpete et al. (2013), attempted to evaluate agricultural tractor engine at different loads and speeds, and found that engine torque decreased on increasing water content. This was explained on the bases that lower heating value of the emulsion, accompanied by less NO_X emissions, but unfortunately associated with an increase in CO. Syu et al. (2014), The performance and emissions of a light-duty diesel engine generator was evaluated using different proportions of diesel-water emulsion (0 – 15 % of water content), and found an increase in thermal efficiency by 1.2-19.9 %, and a decrease of NO_X by 18.3 - 45.4 %. In this study various emulsion blends of diesel-water in the range of 5 -20 % (water volume) with the help of commercially available Tween 20 surfactant will be analyzed. A compression ignition engine will be run at different loads (0 - 100 %) and constant speed 1500 rpm by using these emulsions, and the amount of various gases emissions will be recorded. A comparative discussion concerns the relation between these variables and the obtained gases emission is to be made.

METHODS AND EXPERIMENTS

Diesel – Water Emulsions

Throughout this work, diesel-water emulsions are prepared by mixing various volumes of the two immiscible components, and bring them into emulsion by using an emulsifier. The used emulsifier is a surfactant. In this case the dispersed material is water, and the main component is the diesel as the continuous phase, as oil in water or water in oil Alahmer et al. (2010). The components of the emulsifier are distilled water, diesel fuel which contains the Cetane Index 48 and a surfactant material (Tween 20 and Oleic Acid). The emulsion fuel is prepared by mixing the surfactant materials together by 0.5 % for each type to obtain the HLB, after that, these materials are added and mixed with pure diesel fuel by (79 to 94 %) using a mechanical mixer for 20-25 minutes at 3000 rpm, finally, the distilled water by (0 to 20 %) is added gradually with efficient mixing at ambient laboratory temperature. The stability requirements for the obtained emulsions are to keep the emulsion stable for few days at wide degrees of temperatures Hasannuddin et al. (2014). Considering that the injected fuel emulsion will last for a while in transfer fuel pipes before it is injected inside combustion chamber, the stable emulsion will not separate before entering the combustion chamber Dibofori-Orji (2011). In the present work, four emulsified fuel blends are prepared in the following proportion; 5, 10, 15, 20 water percentage and designated as DW5, DW10, DW15 and DW20 respectively, as shown in table (1).

The physical properties of these emulsions and pure diesel like density, calorific value and viscosity are determined, and presented in table (2). The density are determined using hydrometer; Calorific value using analyser type - P6310 - Bomb Calorimeter and kinematic viscosity using viscometer type - VR 3000 MYR Viscometers, respectively. The results presented in table (2) reveals that an increase in the density and viscosity of the emulsion fuel as well as a reduction of the heating value compared to pure diesel fuel.

Experimental Setup

A single cylinder, 4-stroke, water-cooled direct injection CI engine is used to conduct the experiment needed to judge the best water content among these emulsion fuels. The engine specifications are described in table (3), and the schematic diagram of the experimental setup is illustrated in figure (1). The engine is connected with a rope brake dynamometer as a loading device. The exhaust is supplied with gas emission analyzer device of the type (AVL DIGAS 444) to measure the emissions of unburned hydrocarbons (HC), carbon dioxide (CO_2), carbon monoxide (CO) and nitrogen oxides (NO_X), as well as the smoke opacity is measured using the device of smoke meter of the type (AVL 437C), both supplied by Avl India Private Limited, India.

Experimental Procedure

Before starting the tests, the probes of the exhaust gas analyzer and smoke opacity meter are installed inside the engine exhaust port. Then the engine operated initially with diesel fuel at a speed of 1500 rpm, and then the loads are increased from 0.0 to 12.5, 25, 50, 75 and 100 % by a rope brake dynamometer. When the engine reaches to a steady state, the gas emission constituents are recorded and for every 10 ml consumption of the fuel. For every load, the test is repeated twice to obtain the average optimum values. The fuel tank is drained out of its content, and it is then filled with samples of emulsion fuels (DW5, DW10, DW15 and DW20), and the same of the above steps are followed for every sample of diesel-water emulsion fuels.

RESULTS AND DISSECTION

The tests mentioned in the experimental part conducted on the CI engine using a pure diesel and four samples of diesel-water emulsion fuel designated DW5, DW10, DW15 and DW20. The emissions of NO_X, smoke, HC, CO and CO_2 were recorded and presented in figures (2-6), and the results were discussed in the following paragraphs as indicators for the validity of the engine in concern with the environment pollution. figure (2), concerned with recording the emissions of NO_X for the above-mentioned emulsions compared to that of the only diesel fuel case. It is apparent that the NO_X emission increases on increasing the loads, for all the types of fuels. Possibly this observation can be related to the increase of the cylinder temperature when the engine loads increase Mahmood et al. (2019). It worth to mention that there are significant decrease in the amount of the emitted NO_X for the emulsions fuels compared to diesel only fuel, where it decreased by 11.1, 17.67, 25.8 and 32.5 % for DW5, DW10, DW15 and DW20, respectively. An explanation for this phenomenon is to relate the formation of steam inside the engine cylinder as a result of high temperatures, this steam was generated from water will absorb the produced combustion heat, which consequently decrease the flame temperature, hence decrease the emission of NO_X Marchitto et al. (2018). Similarly, the values for a smoke opacity emitted from fuel of diesel-water emulsions and only diesel fuel versus load were recorded and plotted in figure (3). From the figure, it is possible to observe a similar behavior to that of NO_X; viz. the property is directly proportional with the applied load on the engine. In the same words the intensity of the smoke opacity increased on increasing the loads. Smoke formation is related to a lack of air amount inside cylinder and oxygen content in the fuel, which is reflected with incomplete combustion of the fuel. Also from the figure, it was observed that the all emulsion samples had a less smoke opacity than the diesel fuel. This is the fact that the presence of water content in the emulsifier fuels will aid to reduce the smoke for its increased amount in oxygen in water structure. The smoke opacity decreased by 11.6, 22, 30.4 and 39 % for the DW5, DW10, DW15 and DW20 respectively, compared to the diesel fuel. The emissions of HC for the emulsions fuel and pure diesel versus engine loads are illustrated in figure (4). Usually, the gases leaving the combustion chamber contains unburned hydrocarbons less than 100 ppm as mentioned **by** Patel et al. (2017), which represent the amount of the fuel which didn`t contribute to mechanical work. The unburned HC emissions will reduce the potential energy of the fuel, and it passed to the exhaust without contribution to the overall engine efficiency. From the figure, on feeding the emulsion DW5 with which contain the minimum amount of water as a fuel to the engine, a decrease in the amount of the emitted HC by ~ 8.3 % was observed. Unfortunately, on increasing the amount of water, the case will be reversed, i.e. the emitted HC will increase for the emulsions DW10, DW15 and DW20 by 2, 9.3 and 12.6 % respectively. Although the combustion process is related to the oxygen availability, the temperature of the combustion chamber was reduced due to the formation steam arized from the presence of added additional water (more than 5 % of the emulsion). The emission of CO gas behaves in similar way to that of HC emission as shown in figure (5), concerning the increase in the loads, i.e. generally it decrease for all the used fuels. This behavior can be attributed to efficient combustion due to the availability of more oxygen from water and air. The emulsion DW5 showed the lowest decrease in CO production, were decreased by 11 % while DW10 emulsion is almost coincide to that of pure diesel fuel. But on increasing the amount of water in the emulsions DW15 and DW20, different story can be told, the presence of more water in the fuel will relatively lower temperature of combustion due the formation of more steam; consequently, the conversion of CO to CO_2 will be lower at relatively lower temperature. Such process will relatively increase the emission of CO by 9 and 14.3 % respectively, when compared to the pure diesel. Energy is obtained from fossil fuels through combustion (burning) and refers to reaction of with oxygen (or air which contain 20 % oxygen) to create carbon dioxide CO_2, water, and heat Hegde et al. (2016). The efficient combustion will produce larger amount of CO_2, in other words the increase in the amount of emitted CO_2 is a good indication for the efficiency of the combustion inside the engine cylinder. figure (6) showed the combustion process observed for the diesel and diesel-water emulsion fuels used in this work. Generally, it apparent that on increasing the amount of water in the used fuel emulsions is accompanied with related increase in the emitted amount of CO_2. On increasing the loads, the production of CO_2 was increased by 4, 8.7, 12 and 14.3 % for DW5, DW10, DW15 and DW20, respectively. It is possible to state that the increase in water content of these fuel emulsions will aid the efficiency of combustion significantly. Increased combustion efficiency will be reflected as the decrease in CO content (as shown in figure (5)) and corresponding increase of CO_2 level (as shown in figure (6)).

CONCLUSIONS

Single cylinder 4-stroke direct injection CI engine was used to conduct experiments needed to judge the best emulsions prepared from diesel fuel with various water content. The NO_X, smoke, HC, CO and CO_2 emissions were recorded at different loads, and the results were discussed.

1. The emissions of CO_2 for all emulsion samples were found to be higher than that of diesel fuel.
2. The emissions of NO_X were found to be less by 11.1, 17.67, 25.8 and 32.5 % for the DW5, DW10, DW15 and DW20, respectively.
3. The smoke opacity decreased on increasing water content for the above emulsions, were less by 11.6, 22, 30.4 and 39 % respectively.
4. The HC emissions were found to be less by 8.3 % for DW5 compared to the pure diesel, but on increasing water content, the HC emissions were increased by 2, 9.3 and 12.6 % for DW10, DW15 and DW20, respectively.
5. CO emissions with low water content were less or almost equal with the pure diesel fuel. However it was found that the increase in water content up to 10 % will increase CO emissions. This is the result of incomplete combustion process of the fuel at high temperatures inside cylinder.
6. Generally, using 20 % (by water content) in the emulsion fuel was found to be an effective method to reduce the emissions of NO_X and smoke in CI engine without any modifications to it, in concern with the environmental pollution.

Table (1): Emulsified fuel specifications.

Fuel Type	Diesel (%)	Water (%)	Tween 20 (%) (Surfactant)	Oleic Acid (%) (Surfactant)
DW5	94	5	0.5	0.5
DW10	89	10	0.5	0.5
DW15	84	15	0.5	0.5
DW20	79	20	0.5	0.5

Table (2): Physical properties of all tested fuels.

Property	Diesel	DW5	DW10	DW15	DW20
Density @ 15 °C, kg/m^3	829	836	844	851	860
Calorific value, kJ/kg	42850	41370	40240	39080	37820
Kinematic viscosity @ 20 °C, mm^2/s	2.71	3.14	3.33	3.62	4.80

Table (3): Engine specifications.

Engine Model	Kirloskar
Type	Single cylinder, 4-Stroke, Compression Ignition Engine
Type of Cooling	Water-Cooled
System of Injection	Direct Injection
Stroke	110 mm
Bore	80 mm
Engine Speed	1500 rpm
Compression Ratio	17:1
Rated Power	3.7 kW (5 HP)
Dynamometer	rope brake dynamometer

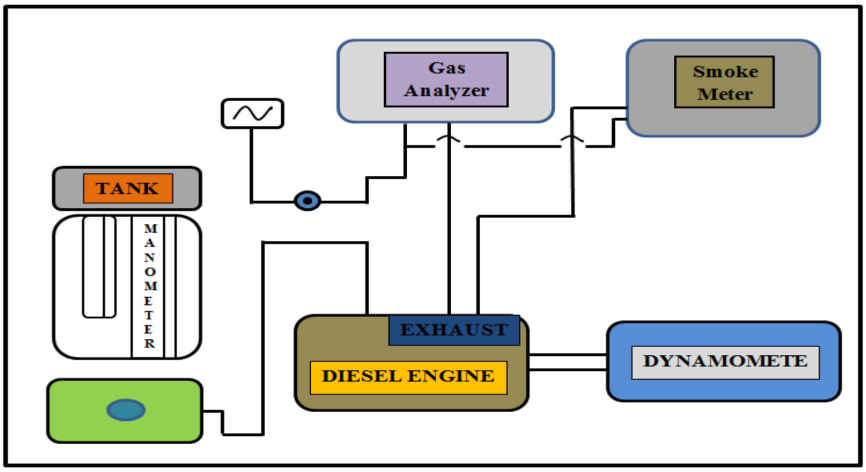

Fig. (1): Schematic Diagram of the Experimental Setup used in this work.

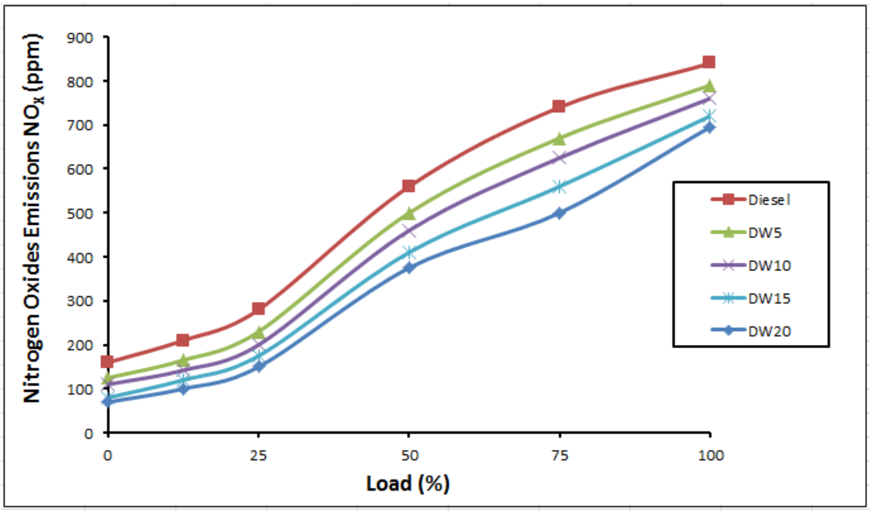

Fig. (2): The NOx emissions of DW5, DW10, DW15, DW20 and pure diesel versus load.

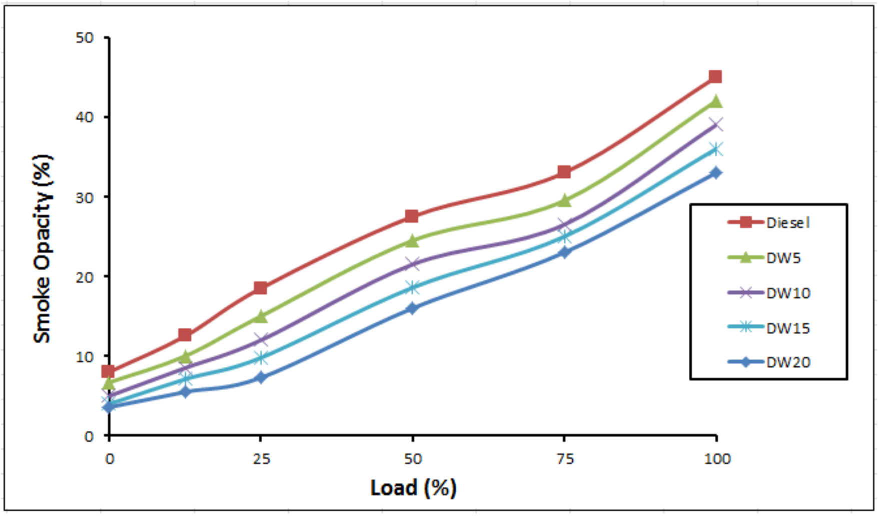

Fig. (3): The smoke opacity of DW5, DW10, DW15, DW20 and diesel fuel versus load.

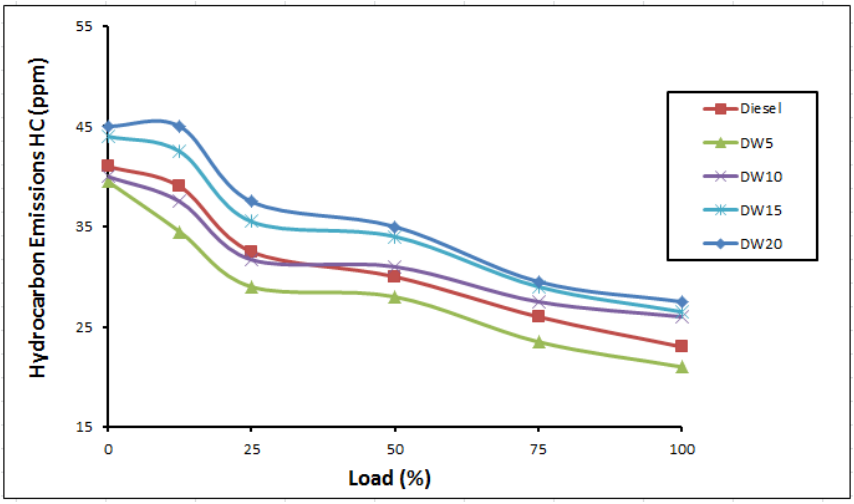

Fig. (4): The HC emissions of DW5, DW10, DW15, DW20 and diesel fuel versus load.

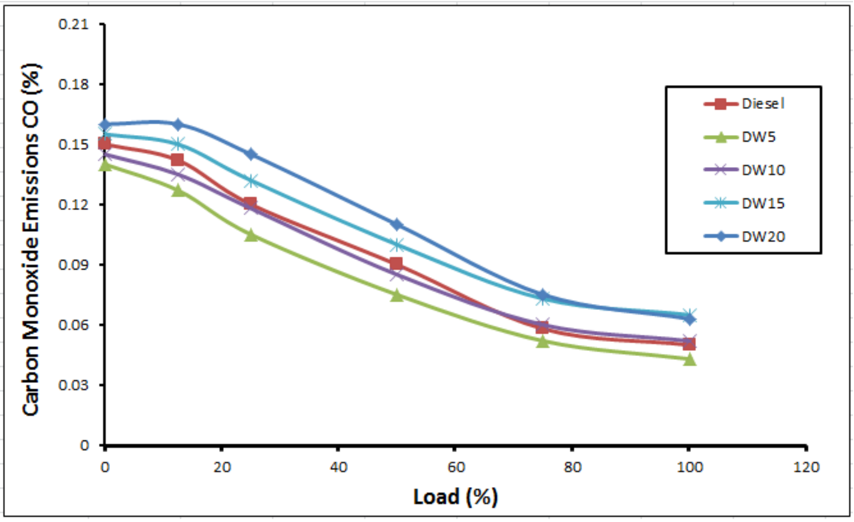

Fig. (5): The CO emissions of DW5, DW10, DW15, DW20 and diesel fuel versus load.

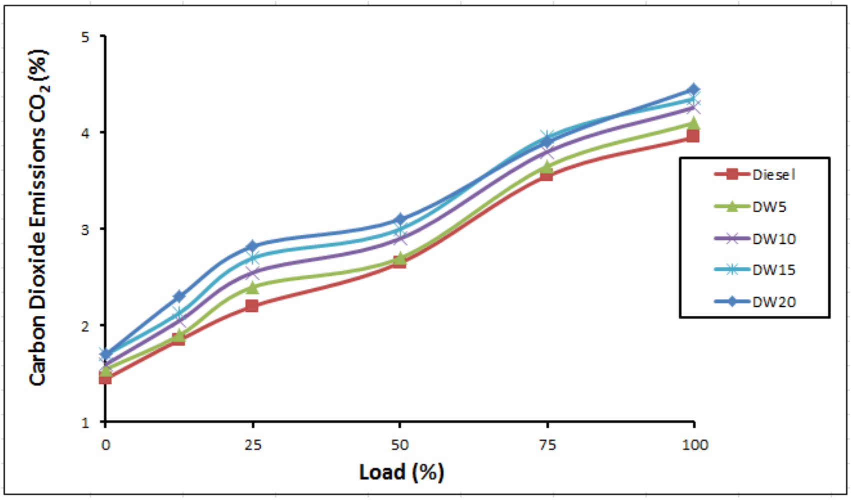

Fig. (6): The CO_2 emissions of DW5, DW10, DW15, DW20 and diesel fuel versus load.

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