SUST Journal of Engineering and Computer Science (JECS), Vol. 17, No. 1, 2016

Influence of Ethanol or Water Injection on the Performance and Emission Parameters of Diesel Engine

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Received:15.06.2014
Accepted:17.09.2014

ABSTRACT-A technology is implemented such that Ethanol or Water is introduced into the intake manifold through an injector while diesel is injected directly into the cylinder. In this paper, comparative experiments were performed on a single-cylinder naturally aspirated, four-stroke, water cooled, and direct-injection diesel engine fueled with Pure Diesel, Ethanol–Diesel, and Water–Diesel (abbreviated as PD, ED, and WD) the Ethanol or Water content of 1.2%–2.8% in volume percentage at injection pressures of 1000 kPa. Moreover, in order to study the effect of Ethanol or Water (DI) with the Diesel on the performance and emissions of the diesel engine when compared to Pure Diesel fuel.The experimental results indicate that the influence of emissions on the full-load engine UBHC emissions is decrease when the ED fuel is used. When the ED fuel is used, the NOx, CO, Exhaust temperature, and excess air decrease. As the fuel oxygen content increases, there are decreases in Brake Specific Fuel Consumption of the ED fuel. And the values of Brake Thermal Efficiency gradually increase. UBHC, CO emissions and excess air of the diesel engine increase with the WD fuel are used. NOx emission reduction by increasing the water content of the fuel. The effects of WD fuels on the Exhaust temperature, Brake Specific Fuel Consumption, and Brake Thermal Efficiency of the diesel engine are reduction.

Keywords: *Emission; Ethanol; Water, Diesel engines, blends, performance.*

المستخلص- اتجهت كثير من الدول لتشريع قوانين تعمل علي تقليل انبعاث غازات العادم من محركات الديزل إلى ادني مستوي لها، بناءً علي ذلك فإن محور هذه الورقة دراسة التأثير الناتج من إضافة الإيثانول أو الماء لمحرك الديزل بالمقارنة مع وقود الديزل فقط. تمت هذه الدراسة في محرك ديزل أحادى الاسطوانة يتم التبريد للمحرك عن طريق الماء وضخ الديزل مباشرة لغرفة الاحتراق الرئيسية، عليه يتم تشغيل المحرك بالوقود الأساسي (الديزل) مع ضخ الايثانول وتارة أخري الماء عند مدخل الهواء للمحرك بنسب تتراوح بين 1.2%–2.8% حجمياً. اختيرت النقاط التشغيلية المعملية لتغطى المدى التصميمي للمحرك وبتحميل أقصي لكل سرعة. إذن الهدف الرئيسي من استخدام تكنولوجيا إضافة الايثانول أو الماء مع وقود الديزل لدراسة تأثيرها علي الغازات الناتجة من الاحتراق وهي اكاسيد النتروجين و أول أكسيد الكربون والهيدركربونات الغير محترقة، الأهداف المصاحبة وهي القدرة النتاجة وكفاءة المحرك والاستهلاك النوعي للوقود ودرجة حرارة غازات العادم ومعامل الهواء الزائد من عملية الاحتراق، ووجدت النتائج في حالة إضافة الايثانول انخفاض في الهيدركربونات الغير محترقة وزيادة في اكاسيد النيتروجين وأول أكسيد الكربون مع زيادة في درجة حرارة غازات العادم والاستفادة القصوى من الطاقة في وقود الديزل، أما في حالة إضافة الماء انخفاض في اكاسيد النيتروجين وزيادة في الهيدركربونات وأول أكسيد الكربون وزيادة في معامل الهواء الزائد وأيضا إمكانية زيادة القدرة الناتجة مع تقليل استهلاك وقود الديزل مع وجود نقصان في درجة حرارة غازات العادم. هذه التجارب تمت بتعديل لا يذكر في محرك الديزل مع تحقيق نتائج كبيرة جدا لتقليل الانبعاث من محرك الديزل وزيادة الأداء في المحرك.

INTRODUCTION

Diesel exhaust contains numerous gaseous and particulate substances some of which are known or suspected of giving rise to adverse health effects in humans.Ethanol is regarded as one of the promising alternative fuels or an oxygen additive in diesel engines with its advantages of low price and high oxygen fraction. However, the addition of ethanol to diesel will increase the ignition delay and combustion noise; therefore, a small addition of a cetane number (CN) improver is helpful to reduce the combustion noise. Some previous work was conducted on the utilization of diesel–ethanol blends in a compression ignition (CI) engine [1]. Ethanol has been added to gasoline for years to replace some of the imported oil used in light-duty gasoline vehicles.

Additionally, several demonstration programs have explored the use of ethanol in diesel engines. Today, there is a renewed interest in ethanol/diesel blends for their potential to help reduce emissions from current and future diesel engines [2]. The use of ethanol in urban areas can reduce hazardous emissions. Some studies show that this benefit might be of minor importance if compared to the use of modern diesel engine equipped with diesel particle filters.

However, ethanol-diesel blends in CI engines have performed better than pure diesel in many trials, with higher energy efficiency and lower PM (smoke), NOx and carbon dioxide (CO_2) emissions [3]. Among the renewable liquid fuels, ethanol is a neat and clean burning fuel for compression ignition engines. Also, high calorific value, lesser sulphur and ash contents, less smoke density show that this fuel is worth to be used for power generation. Environmentally, the use of ethanol blends has assisted in reducing carbon monoxide (CO) and toxic emissions.

Use of ethanol-blended fuels can reduce the net emissions of greenhouse gases by as much as 37.1%. It is expected that once ethanol is made from cellulose, the green house gas emission reduction will further improve.

Unlike hydrocarbon based fuels, the sulphur content of ethanol is closed to zero and hence, the environmental damage caused by sulphuric acid is reduced. Moreover, ethanol takes away more CO_2 from the atmosphere during its production than is added to it by its later combustion. Therefore, it alleviates the increasing of CO_2 content of atmosphere [4]. Ethanol has been used as a fuel for compression ignition engines, and can be fermented and distilled from biomasses. As such, ethanol fuel can be considered a renewable fuel. In addition, ethanol (C_2H_5OH) is a pure substance. It contains an oxygen atom and can thus be viewed as a partially oxidized hydrocarbon. As a fuel for CI engines, ethanol has certain advantages over diesel fuel including reductions of soot, carbon monoxide (CO) and unburned hydrocarbon (HC) emissions. Unfortunately, ethanol is currently unable to be used extensively due to limitations in technology and economic and regional considerations [5].

Complete combustion of ethanol forms carbon dioxide and water vapor [6]:

$$C_2H_5OH+3O_2\rightarrow 2CO_2+3H_2O \qquad (1)$$

The dual-fuelling experiments were performed in a single-cylinder automotive-size diesel engine. Ethanol was supplied into the intake port using a conventional port-fuel injector (PFI) and the diesel direct-injection was conducted using a common-rail injection system. In-cylinder pressure and engine-out emissions of smoke, NOx, HC and CO were measured for various ethanol energy fractions at a fixed total energy of ethanol and diesel per engine cycle. In-cylinder pressure traces were further analyses to determine the heat release rates, ignition delay, combustion phasing, and burn duration that explain the causes of observed trends in the efficiency and emissions [7].

NOx formation in a diesel engine is primarily a function of local combustion temperatures in the combustion space. It has long been known that water has a positive influence on reading NOx formation by cutting temperature peaks in the process. Various methods of introducing water have been evaluated and fying the fuel with water, humidification of the combustion air, and direct water injection into the combustion space [8].

Fumigation is where liquid water is injected into the intake manifold upstream of the intake valve. The fumigation technique has been shown to reduce NOx emissions in DI Diesel applications but suffers from the drawback that the liquid water in the combustion chamber is typically in areas where it is less effective at reducing emissions. Therefore, fumigation requires approximately twice the liquid volume for the same reduction in engine out NOx when compared to Direct Water injection.

Additionally, liquid water present after combustion can contaminate the oil and increase engine wear [9].

NO is formed during the post flame combustion process in a high temperature region. The most widely accepted mechanism was suggested by Zeldovich[10]. The principal source of NO formation is the oxidation of the nitrogen present in atmospheric air. The nitric oxide formation chain reactions are initiated by atomic oxygen which forms from the dissociation of oxygen molecules at the high temperature reached during the combustion process [10]:

$$N_2+O \rightarrow NO+N \quad (2)$$

$$N+O_2 \rightarrow NO+O \quad (3)$$

$$N+OH \rightarrow NO+H \quad (4)$$

MATERIAL AND METHODS

The engine used in the present study is a four stroke, water cooled, single-cylinder, direct-injection (DI) at a rated power of 5.9 kW and a rated speed of 1600rpm. The engine has an open type combustion chamber, which is shaped as a hemi-sphere bowl in piston. Table 1 lists the specifications of the engine used in the experimentation reported in this work. Since a single-cylinder engine was used, pressure fluctuations in the intake and exhaust pipes were identified as a potential issue. To minimize them, large-volume surge tanks were placed in both intake and exhaust sides.

For ethanol or water injection, the engine intake manifold was modified to install a port fuel injector (PFI: Bosch EV6) with six holes. The injector was located close to the intake port so that the sprays are directed toward the valve top surface, similar to SI engines [Ethanol utilisation in a diesel engine using dual-fuelling technology]. The ethanol or water injection pressure was held constant at 1 MPa.

The power output of the tested engine was measured using a hydraulic dynamometer (DYNOmite, Land&Sea) connected to a DYNOmite data acquisition system (DYNOmite-Pro 28 channel data-acquisition board with DYNO-MAX 2010 software) to record true engine crankshaft Hp, torque and speed (at up to 1000 readings per second) while automatically applying inertia compensation and SAE correction factors for air temperature, barometric pressure, and relative humidity. The exhaust gas emissions and temperature were measured by an exhaust gas analyzer.

The SV-5Q exhaust gas analyzer is used directly to measure UBHC, CO and CO_2 in the exhaust gas and inspects the density of NO and O_2 via electrochemical sensor so as to calculate excess air coefficient, λ, formed during combustion. For measuring the intake air flow of the engine, an air flow meter turbine (DYNOmite, Land&Sea) is used. This low inertia turbine measure the intake air flow through a plenum (to dampen intake pulsations) attached to the engine. The volumetric flow rates of the diesel fuel and ethanol or water were measured using graduated burettes and stopwatches. All experiments were performed after ensuring the full engine warm-up.

Table 1: Engine specifications

Engine type	GKW
Bore (cm) × stroke (cm)	8.75 x 11
Displacement (cm^3)	631.56
Compression ratio	17.5:1
Fuel	Diesel, Ethanol or Water
Ignition source	Diesel injection
Fuel injection	Direct injection
Injection system	Pencil-type, three-hole nozzle
Combustion chamber	Hemispherical bowl in piston
Number of valves per cylinder	Two
Rated power (HP)	7.5@ 1600 rpm

The experimental location selection at The King Saud University Test Laboratory was used for the research. The facilities included hydraulic dynamometer and an exhaust removal system. Diesel engine with no or fewer modification insert nozzle inside and centering manifold see Figure 1 connecting another end to pump. The specification of the pump dosing rate 2.1 l/h-10 bar.

The testing procedure is as follows. After completion of standard warm up procedure, the engine was tested on a matrix of six speeds started in diesel-only mode. Then the pump and fuel injector were turned on to inject ethanol or water into the intake manifold. The observation made during the test for determination of various engine parameters, such as brake power, torque, engine speed, air flow rate, and exhaust temperature, time for a certain amount of diesel consumption and ethanol or water consumption. The SV-5Q exhaust gas analyzer was used to measure the CO, CO_2, HC, O_2, NOx and λ.

RESULTS AND DISCUSSION

Figure 2 shows the variations of NOx emissions of pure diesel, WD, and ED for all tests, as engine speed increases as NOx decreases for all condition tests. For diesel engines the most important pollutant is NOx which is temperature dependent, via thermal Zel'dovich mechanism [10]. NOx are highly active ozone precursors playing an important role in the smog chemistry. Here also the pure diesel line shows the medium value of NOx between WD and ED for all test conditions. This is because ethanol addition produce higher heat releases rate at the oxygenated fuel, which higher the peak combustion temperature and hence increases NOx emissions.The minimum NOx emission is 149 ppm at 1600 rpm in case WD condition. According to pure diesel NOx emission values, the highest change is 71% at 800 rpm in case WD condition, the lowest change is -122% at 600 rpm in case ED condition. Due to the fact that water in the form of micrometer sized droplets exerts some positive effects on the combustion of the fuel and exhaust emissions, frequently NOx. Similar behavior NOx emissions increase with increasing ethanol fraction [7]. Such behavior of ethanol–Diesel blends has already been observed [11]. Contradicting behavior for emissions was in the same engine using addition of ethanol into diesel with, biodiesel in blends and EGR [13], water mixtures [14], Acetone–Butanol diesel blends [15], ethanol-diesel blends [16], and ethanol fumigation on diesel engine [17]. So not stable the NOx emissions for ethanol–diesel blends was same engine using [19].

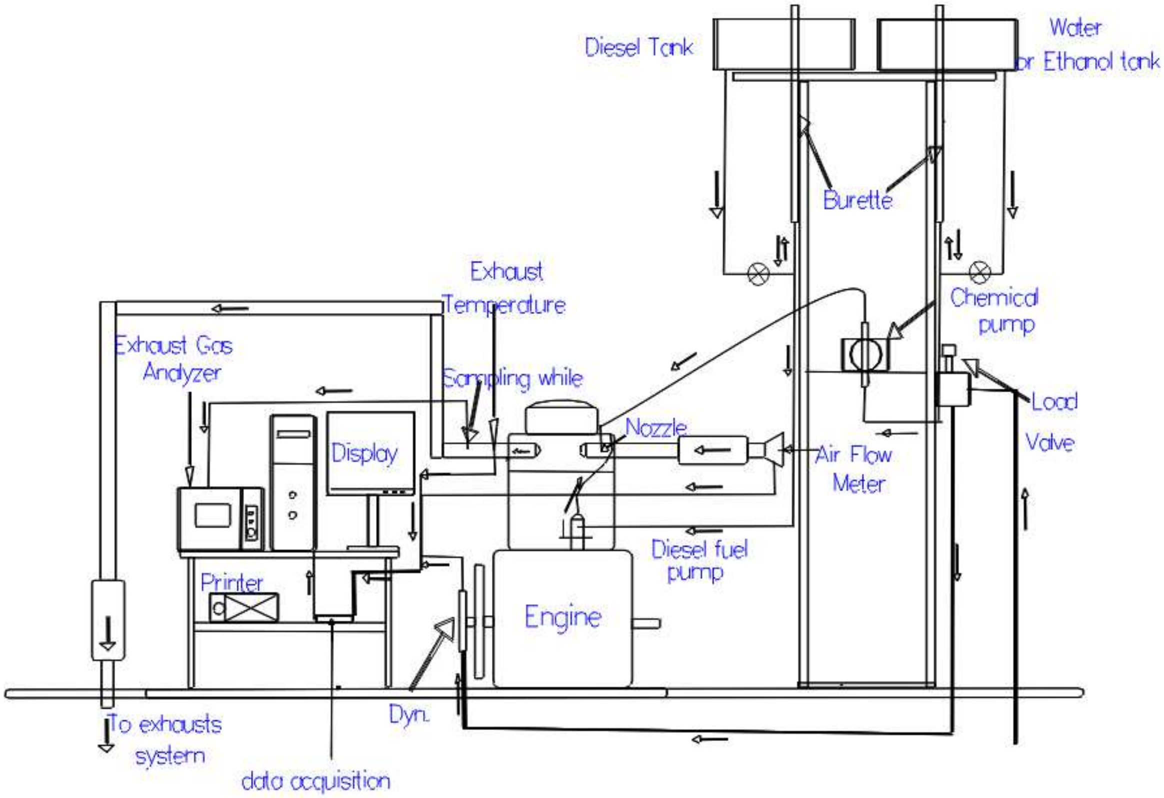

Figure 1: Schematic arrangement of the engine test bed, instrumentation and data logging system

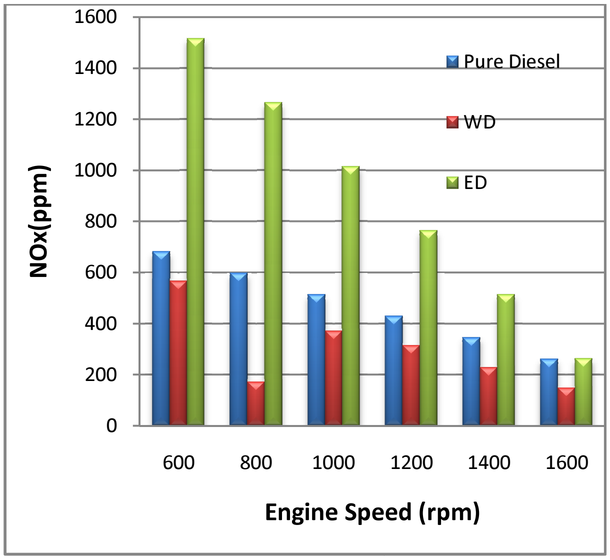

Figure 2: Variation of NOx with Engine speed

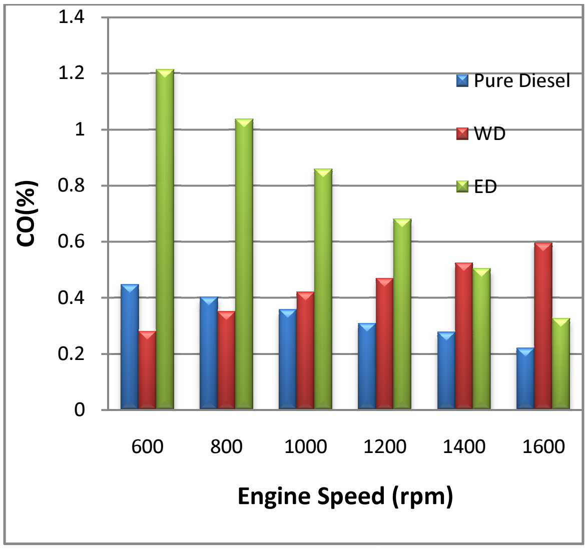

Figure 3: Variation of carbon monoxide with Engine speed

The production of the lower combustion temperature by WD as well as by reduction temperature peaks in the combustion. Similar trend for emissions was seen in the same engine using, steam injection as the added fuel [20], direct water injection [21], diesel-water emulsion fuel [22].Figure 3 shows the variations of carbon monoxide percentage emissions of pure diesel, WD, and ED for all tests, as engine speed increases as carbon monoxide percentage decreases for pure diesel, and ED. Also found CO increases with WD as increases engine speed. Because the reduced percentage of CO due to their excess air operation. Here also the pure diesel columns show the minimum value of carbon monoxide percentage. There are two main reasons, the higher thermal efficiency, better and complete combustion. The reasons, firstly for the complete combustion is that the molecules of ethanol contain some amount of oxygen that takes part in combustion, secondly constant flow rate of ethanol that give high value of CO on low value of engine speed. The minimum CO emission is 0.22(%) at 1600 rpm in case pure diesel condition. According to pure diesel CO emission values, the highest change is 37% at 600 rpm in case WD condition, the lowest change is -172% at 600 rpm in case ED condition. This happens because with increase in water the temperature inside the cylinder decreases slowing down the combustion of carbon, as a result of which incomplete combustion occurs. Suggest the resulting pressure injection pump. At high speeds, due to the high temperature in cylinder and oxygen content of ethanol, the oxidation of CO is improved, thus, the CO emissions of ED becomes higher than pure diesel emissions. Similar trend ethanol is introduced into the intake manifold [7, 17]; ethanol diesel fuel blends [13, 15]. CO was reduced when the engine ran at and above its half loads, but was increased at low loads and low speed when used ethanol–diesel blends [19]. The CO emissions enhance with optimum steam injection rate at all engine speeds. However, it is seen that the increase in the emission is within the limits of uncertainty when considering measurement accuracy [20]. Dissimilar behavior using, ethanol–diesel blends [12, 25], diesel-water emulsion fuel [18], direct water injection [24].

Figure 4 shows the variations of UBHC emissions of pure diesel, WD, and ED for all tests, as engine speed increases as UBHC increases for pure diesel and with WD. Also found CO increases with ED as increases engine speed. Addition of ethanol will lead to complete combustion so that UBHC emission should reduce. The minimum UBHC emission is 30 (ppm) at 600 rpm in case WD condition.

According to pure diesel UBHC emission values, the highest change is 92% at 1600 rpm in case ED condition, the lowest change is -639% at 600 rpm in case ED condition. In summary, the higher latent heat of vaporization of ethanol and oxygen content of ethanol are the main reasons for the changes of gaseous emissions. Engine-out emissions have been main discussion points in the previous studies and there is a consensus that the UBHC and CO emissions increase [7, 17]. It was explained that some ethanol is trapped inside the crevice resulting in increased UBHC emissions ethanol–diesel blends [13, 15, and 19]. Almost all studies report benefits of steam substituting diesel in reducing CO emissions [20]. However, when a wide range of diesel injection timings are tested, the UBHC emission is found to increase with increasing water emulsion [22] or direct water injection [24]. Dissimilar behavior for emissions was in the same engine using, ethanol–diesel blends [12, 25], and water-diesel emulsions [23].

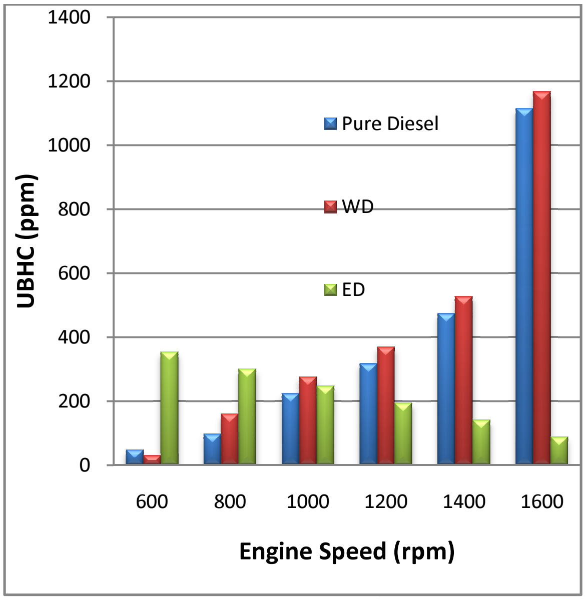

Figure 4: Variation of UBHC with Engine speed

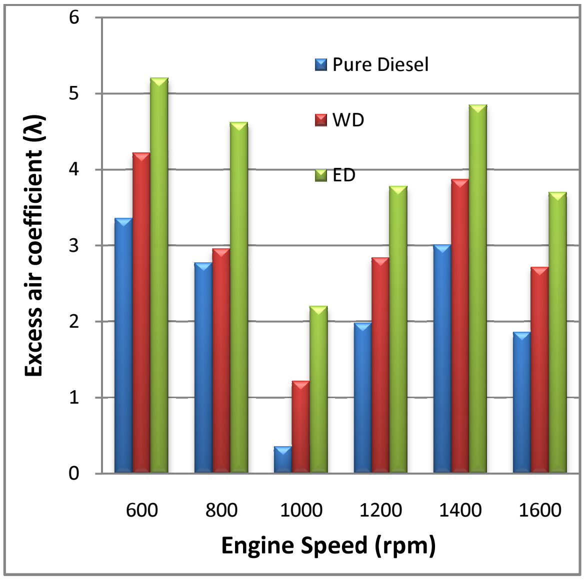

Figure 5: Variation of excess air coefficient (λ) with Engine speed

Figure 5 shows the variations of excess air coefficient (λ) of pure diesel, WD, and ED for all tests, as engine speed increases as excess air (λ) decrease to 1000 RPM, after that increase to 1400 RPM, then decreases to maximum RPM for all condition tests. However for ED or WD the excess air (λ) is higher than that of purediesel fuel, because of ethanol is an oxygenated fuel and in water test may be decreases temperature intake manifold. Ethanol has lower stoichiometric air/fuel ratios than biodiesel and diesel fuel, thus blending ethanol into biodiesel leads to leaner combustion [12].

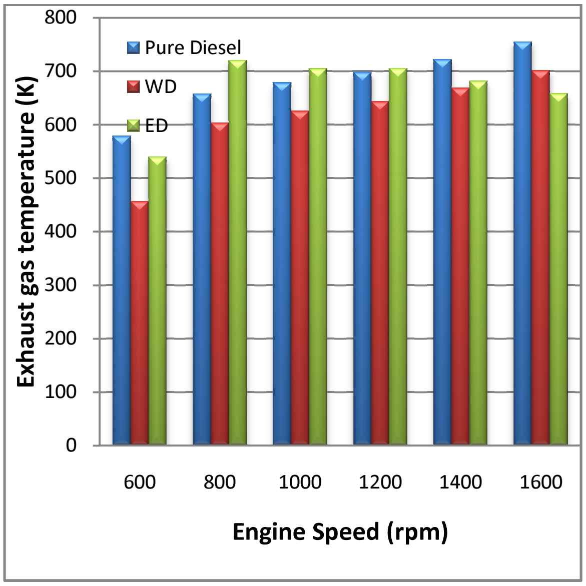

Figure 6: Variation of Exhaust gas temperature with Engine speed

According to pure diesel λ values, the highest change is 7% at 800 rpm in case WD condition, the lowest change is -517% at 1000 rpm in case ED condition. Ethanol has low viscosity than diesel fuel which makes the ethanol easily to be injected and atomized and mixed with air. Due to having high oxygen content, high stoichiometric air–fuel ratio, high hydrogen–carbon ratio and low sulfur content, ethanol emits less emission. Cooling effect in the intake process and compression stroke. As a result the volumetric efficiency of the engine is increased and the required amount of the work input is reduced in the compression stroke.

Figure 6 shows the variations of Exhaust gas temperature of pure diesel, WD, and ED for all tests. The effect on the exhaust gas temperature of the engine, with increase in engine speed on the engine the exhaust gas temperature increases at pure diesel and WD. Seen again figure at ED increases gas temperature between speed (600-800) rpm, no change between speed (1000-1200) rpm, and decreases to maximum speed. However for WD the gas temperature is lower than that of the pure diesel fuel at all tests. Another for ED the gas temperature is higher than pure diesel at speed between (800-1200) rpm; else speeds are lowers, whereas at low and part brake power operation it is observed to be greater than that of the pure diesel fuel.

For other operation conditions not much more variation is observed for the gas temperature except for the higher brake power. The minimum exhaust gas temperature is 456 (K) at 600 rpm in case WD condition. According to pure diesel exhaust gas temperature values, the highest change is 21% at 600 rpm in case WD condition, the lowest change is -10% at 800 rpm in case ED condition. However for the ED or WD are observed to be lower than that of purediesel. This may be the results of high A/F. The lower exhaust gas temperature indicates that the effects of dissociation are significantly reduced that may reduces the pollutant CO. Similar results are also found in other studies [21, 22].

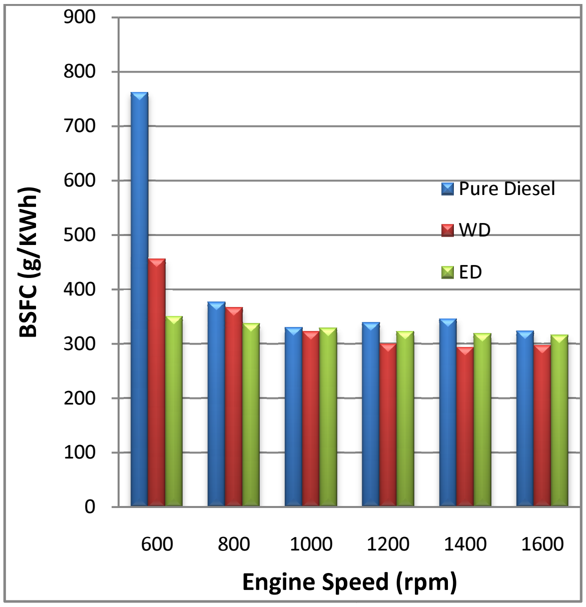

Figure 7: Variation of Brake Specific Fuel consumption with Engine speed

Figure 7 shows the variations of BSFC of pure diesel, WD, and ED for all tests, as engine speed increases as BSFC decreases for all the conditions tested. By observing related results at 1400 rpm engine condition, minimum values of BSFC for pure diesel, with ED, and with WD were found, 341.62 g/KWh, 320.24 g/KWh and 298.86 g/KWh respectively.

Was found to be higher, at all conditions than that of pure diesel. This is caused due to combined effect of temperature combustion. The minimum BSFC is 294 (g/KWh) at 1400 rpm in case WD condition. According to pure diesel BSFC values, the highest change is 54% at 600 rpm in case ED condition, the lowest change is 0% at 1000 rpm in case ED condition.

Due to the improved BSFC of diesel, the study showed a higher power output than conventional diesel. However advancing the injection water or ethanol improved BSFC but also resulted in an increase in NOx. A further study was then conducted using a steam injection as the added fuel research engine [20].

Similar behavior for BSFC was in the diesel engine using, ethanol–diesel blends [13, 25], diesel-water emulsion fuel [22], and direct water injection [24]. Contradicting behavior for emissions was in the same engine using, addition of ethanol into diesel [17, 19].

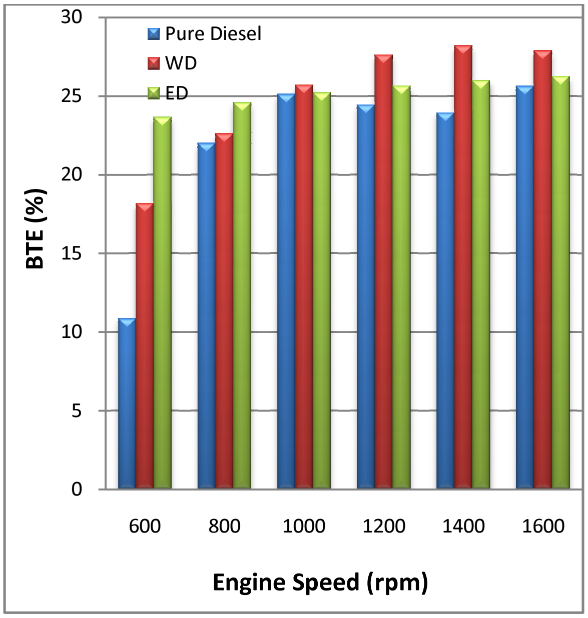

Figure 8: Variation of Brake Thermal Efficiency with Engine speed

Figure 8 shows the variations of Brake thermal efficiency (BTE) of pure diesel, WD,ED for all tests, as engine speed as increases BTE. However, decrease between conditions at (1200 to 1400) rpm for the pure diesel fuel tested. The reason for decrease of BTE at this region is the occurrence of knock. More admission of cetane fuel at the time of overload increases tendency of knock. By observing related results at full engine speed, maximum values of brake thermal efficiency for pure diesel, ED and WD, were found, 25.59%, 26.23% and 28.13 %, respectively.

As compared to pure diesel, WD gives good combustion fuel. See again results no change in BTE at condition 1000 rpm. Ethanol has high laminar flame propagation speed, which may complete the combustion process earlier, this improves engine thermal efficiency. Similar behavior for BTE was in the same engine using, a dual-fuelling technology is implemented such that ethanol is introduced into the intake manifold using, a port-fuel injector while diesel is injected directly into the cylinder [7, 17], ethanol–diesel blends [15], steam injection as the added fuel [20], diesel-water emulsion fuel [22], and direct water injection [24]. Contradicting behavior for Brake thermal efficiency was in the same engine using, addition of ethanol into Diesel [19].

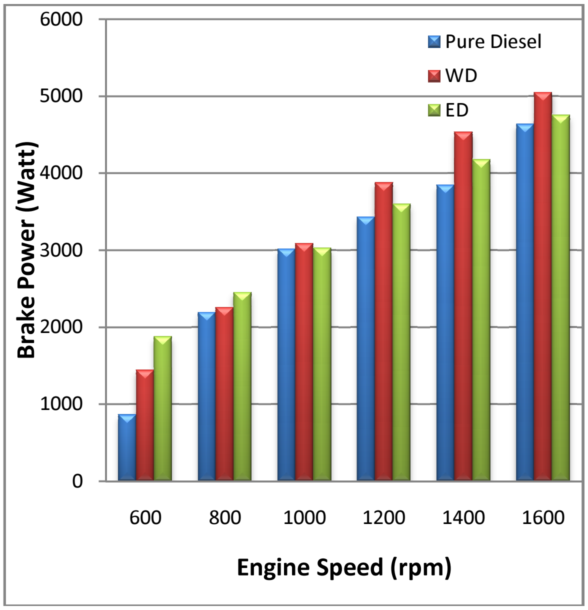

Figure 9: Variation of Brake Power with Engine Speed

Figure 9 shows the variations of Brake Power of pure diesel, WD, and ED for all tests, as engine speed increases brake power increases. By observing related results at full speed engine condition, maximum values of brake power for pure diesel, ED and WD, were found, 4638.7 W, 4751.7 W and 5049.1 W respectively. As compared to pure diesel, WD gives good combustion fuel. See again results no change in brake power at condition 1000 rpm. Similar behavior studies [7, 13, and 25].

One group of researchers who tested diesel-water proportions blended in diesel, it was reported that the emulsion - component in diesel increases brake power [20, 21]. A summary of the overall effects of WD or ED with diesel fuels from publications reviewed in this paper. Some of the literature reports an increase in fuel consumption as well as a decrease in rated power. However the majority of the studies have shown that WD or ED with diesel fuels do not cause any loss of power whilst showing significant improvements in all regulated emissions. In general WD or ED fuels give a viable solution to retaining engine performance and reducing legislative emissions.

CONCLUSIONS

Experimental investigations were performed on single cylinder DI diesel engine. Tests conducted on water cooled diesel engine. Engine can be run with diesel fuel blends water or ethanol by direct injection in intake manifolds without any abnormality and engine modification. Experiments were conducted using ethanol or water and it was proved that engine running using ethanol increased the power output and reduced emissions. Moreover, ethanol was renewable energy source and was nontoxic and biodegradable. It was noticed that most ethanol contained substantial amount of oxygen in their molecular structure and sulphur content was almost negligible. The major findings from this study are:

- The emissions of CO and NOx increased with ED, while UBHC emission increased at low engine speed and decreased at high engine speed when compared to the Pure Dieselcase.
- The emissions of NOx decreased with WD, while UBHC. CO increased at low speed and decreased at high speed when compared to the Pure Dieselcase.
- Brake Thermal Efficiency and Brake power increases with ED or WD substitution at all loads.
- Brake Specific Fuel Consumption decreases with ED or WD when compared to Pure Diesel fuel.
- The excess air (λ) increased with ED or WD when compared toPure Diesel case.
- The Exhaust Gas Temperature increased, in medium speed with ED, and decreased for another tests condition when compared to the Pure Diesel case. Decreased with WD when compared to the Pure Diesel case.

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