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PERFORMANCE, EMISSION AND EFFICIENCY ANALYSIS OF A DIESEL ENGINE OPERATED WITH DIESEL AND DIESEL-ETHANOL (E20) BLEND

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Abstract

Conventional fossil fuel sources face with scarcity risk. Therefore, researchers are trying to find new renewable alternative energy sources which have potential to replace conventional sources.

Alcohol and biodiesel are prominent sources among others. In this study, performance and emission characteristics of a diesel fuel and ethanol added (20% vol.) diesel fuel (E20) operated compression ignition engine was studied in between 1000 - 2600 engine speed. Torque, power, specific fuel consumption curves as performance and carbon monoxide (CO), nitrogen oxides (NOx) curves as emission parameters with respect to engine speed were obtained. Energy and exergy efficiency curves versus engine speed in order to assess the system thermodynamically were also obtained. Results showed that, while torque, power, CO emission were decreased, specific fuel consumption, NOx emission were increased with use of diesel-ethanol blends. On the other hand, both energy and exergy efficiency values were decreased when alcohol was added to diesel fuel.

Keywords

Alcohol, Diesel Engine, Energy, Exergy

1. Introduction

Petroleum based fuels are major energy sources over worldwide. Unfortunately, these primary energy sources have faced with scarcity problem in recent years. Besides that, global warming, waste policies and unstable prices of fossil fuels have directed scientists to search alternative fuels in order to replace fossil based fuels (Kalargaris, Tian & Gu, 2001). Gasoline and diesel are the most popular of all fossil based fuels. Especially diesel fuel is more preferable and has more advantages than gasoline since its lower price. It is widely preferred not only in transportation sector but also in the industrial sectors such as power generation industry (Yilmaz & Atmanli, 2017).

Use of alcohols and their blends with diesel have been attractive for researchers since the beginning of 21st century (Venu & Madhavan, 2017). Besides releasing less pollutant such as particulate matter, unburnt hydrocarbon and carbon monoxide, it requires little or no engine modification for usage (Tosun, Yilmaz, Ozcanli & Aydin, 2014). In literature, there are various studies about performance, emission and combustion characteristics of alcohol fueled diesel engines (Datta & Mandal, 2016; Atmanli, 2016; Zhang, Nilsson, Björkholtz, Munch & Denbratt, 2016; Tutak, Lukacs, Szwaja & Bereckzy, 2015; Ali, Abdullah, Mamat & Abdullah, 2015; Li, Zhang & Li, 2016; Wei et al., 2017).

The efficient use of fuels is very important issue. In this regard first and second law analysis of thermodynamics is good techniques for evaluation of efficient and effective usage of fuels (Khoobbakht, Akram, Karimi & Najafi, 2016). At a given state, exergy of a system (availability) can be explained as the maximum extractable power from the system when it reaches thermal, mechanical and chemical equilibrium with its surrounding while performing a reversible process. Thermal equilibrium occurs when system and its surrounding temperatures are equal. Mechanical equilibrium occurs when there is no pressure gradient between system and its surrounding. On the other hand, there is a chemical equilibrium when compounds in system do not interact with its surrounding (Li, Jia, Chang, Kokjohn & Reitz, 2016).

Energy efficiency can be defined as the ratio of useful energy output to input energy supplied to the system. Exergy efficiency totally differs from energy efficiency. According to Dincer and Rosen (2013), exergy efficiency is a measure of reaching to ideal case (reversibility). In other words, it provides a measure of how nearly the operation of a system approaches the theoretical upper limit (ideal) (Dincer & Rosen, 2013).

In this study, performance and emission characteristics of a compression ignition engine fuelled with diesel and diesel-ethanol (E20) blends were evaluated. Energy and exergy efficiency of both two fuels were also determined with respect to engine speed.

2. Materials and Methods

2.1 Engine Tests

All engine tests were performed on a naturally aspirated, four cylinder, four stroke, and direct injection compression ignition engine in Çukurova University Automotive Engineering Laboratory. The engine specifications were given in Table 1.1.

Table 1: *Engine specifications*

Brand - Model	Mitsubishi Canter - 4D34-2A
Configuration	In line 4
Displacement	3907 cc
Bore	104 mm
Stroke	115 mm

Power	89 kW @ 3200 rpm
Torque	295 Nm @ 1800 rpm

Engine torque was measured with the aid of a hydraulic dynamometer. TESTO 350 XL gas analyzer is used to measure exhaust emissions. Emission data are collected by the help of a computer program.

2.2 Energy and Exergy Efficiencies

Thermal efficiency (energy) of the engine can be calculated with the following formulation (Tat, 2011):

$$\eta = \frac{\dot{W}}{\dot{E}_{fuel}} \quad (1)$$

$$\dot{E}_{fuel} = \dot{m}_{fuel} H_u \quad (2)$$

Where, $\dot{E}_{fuel}$, energy input rate; H_u, lower heating value; $\dot{m}_{fuel}$, fuel mass flow rate; $\dot{W}$, work rate.

Second law efficiency (exergy) of the engine can be calculated with the following formulation (Tat, 2011):

$$\psi = \frac{\dot{Ex}_W}{\dot{Ex}_{in}} \quad (3)$$

$$\dot{Ex}_{in} = \dot{m}_{fuel} \varepsilon_{fuel} \quad (4)$$

$$\varepsilon_{fuel} = H_u \varphi \quad (5)$$

$$\varphi = 1.0401 + 0.1728 \frac{h}{c} + 0.0432 \frac{o}{c} + 0.2169 \frac{a}{c} \left(1 - 2.0628 \frac{h}{c}\right) \quad (6)$$

Where, $\dot{Ex}_W$, exergy work rate; $\dot{Ex}_{in}$, exergy input rate; ε_{fuel}, specific exergy of fuel; φ, chemical exergy factor for liquid fuels; h, c, o *and* a are mass fractions of hydrogen, carbon, oxygen, and sulfur contents of the fuels.

For calculations, chemical formulas of diesel and ethanol fuels can be taken as $C_{14}H_{28}$ and C_2H_5OH (Sayin, 2010). Lower heating values (kj/kg) of diesel and E20 fuels were measured as 43965 and 39896, respectively.

3. Results and Discussions

The change of torque with respect to engine speed for two fuels can be shown from the following Figure 1. There is 5.01% torque reduction with usage of alcohol mixture. The reason can be explained by the fact that alcohol has lower calorific value.

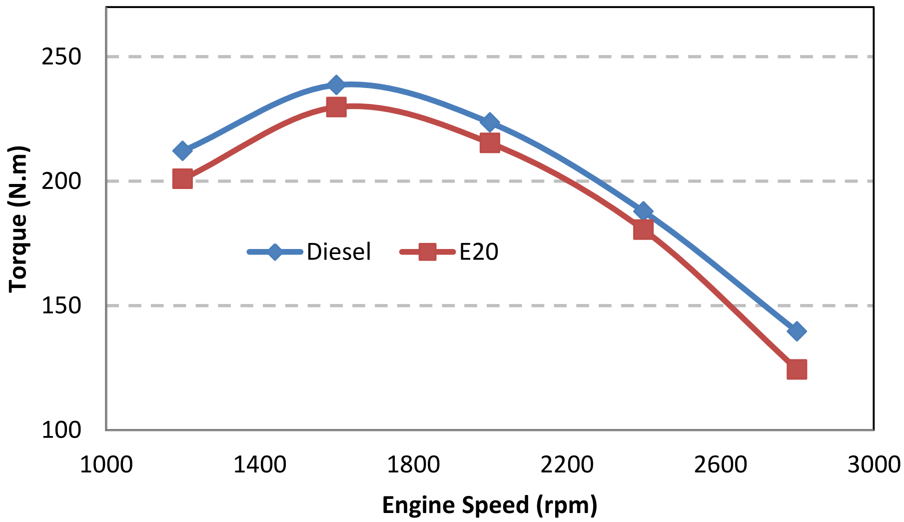

Figure 1: *Torque vs engine speed*

Torque is energy. Power is energy per unit time. Engine power can be calculated with multiplication of torque with angular velocity. Therefore in power curve, the same trend is expected with torque curve. In Figure 2, 5.44% decrement of power with use of alcohol can be explained with same reasons in Figure 1.

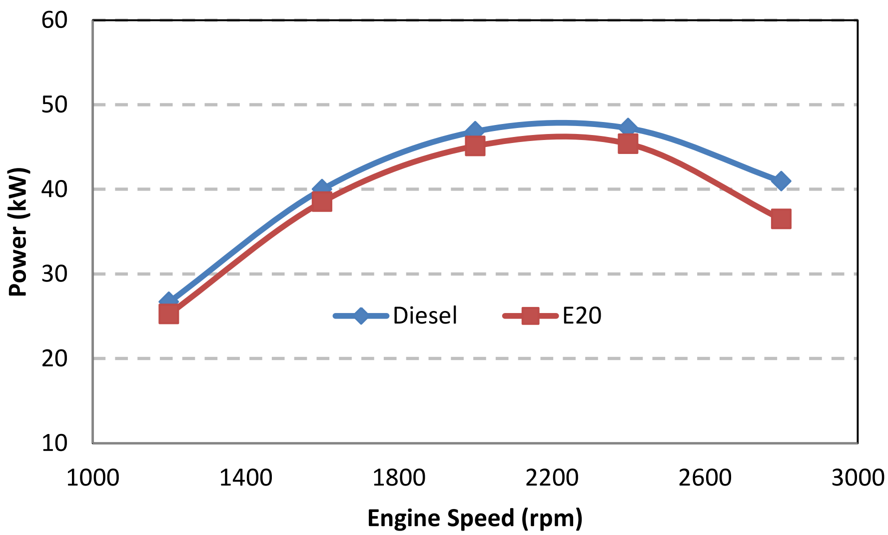

Figure 2: *Power vs engine speed*

Specific fuel consumption is amount of fuel injected in order to obtain unit power per unit time. It is very useful parameter to compare different engines on subject of fuel economy. There is 12.56% increment in specific fuel consumption when alcohol mixture used. Lower calorific value means to inject much more fuel to obtain same power values. In Figure 3, the increment on specific fuel consumption can be explained by this reason.

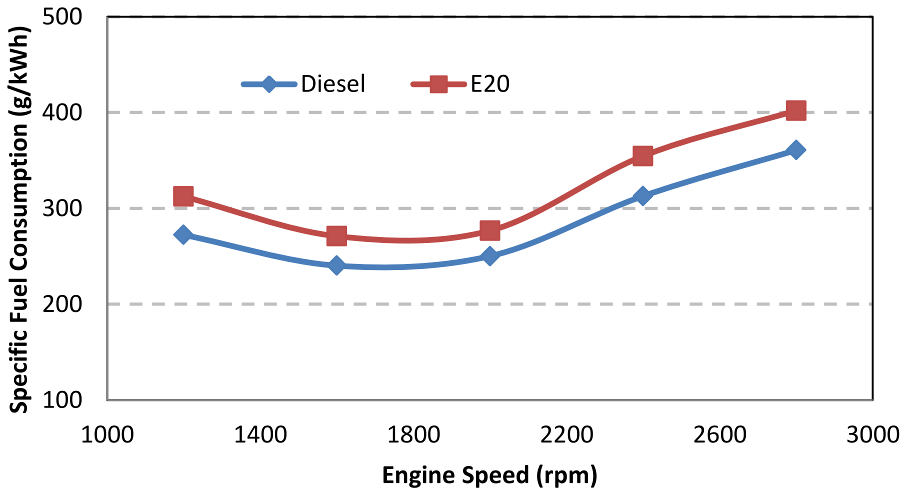

Figure 3: *Specific fuel consumption vs engine speed*

Carbon monoxide is formed by incomplete combustion of fuels and mostly produced from fuels which do not have oxygen content in their chemical structure (Sayin, 2010). Since ethanol contains extra oxygen content in its chemical structure, it cause to oxidizing much more carbon and it prevents incomplete combustion. Therefore, there is 3.34% decrement in CO emission when ethanol is added to diesel fuel and it was shown in Figure 4.

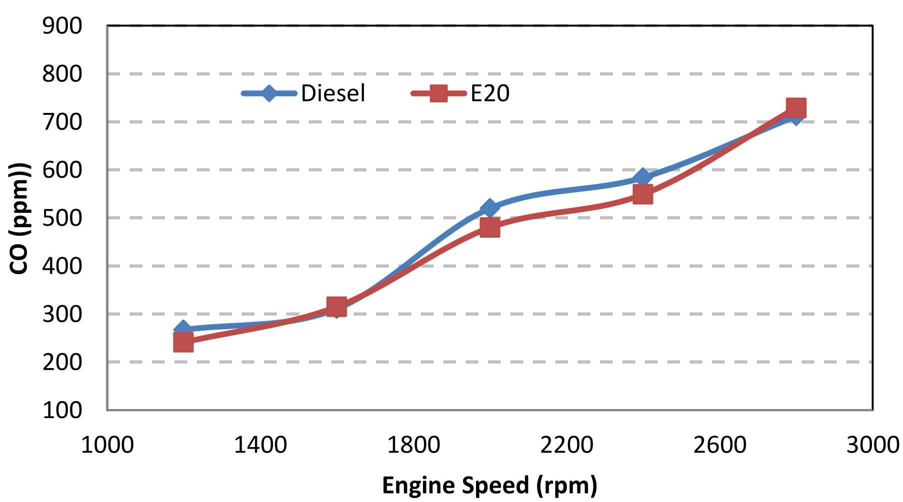

Figure 4: *Carbon monoxide vs engine speed*

Extra oxygen content of alcohol enhances the combustion (Tosun et al., 2014). This situation increases the in-cylinder temperature and cause to increase NOx emissions. When alcohol mixture is used, there is 5.5% increment on NOx emission with respect to diesel. Figure 5 showed NOx emissions versus engine speed.

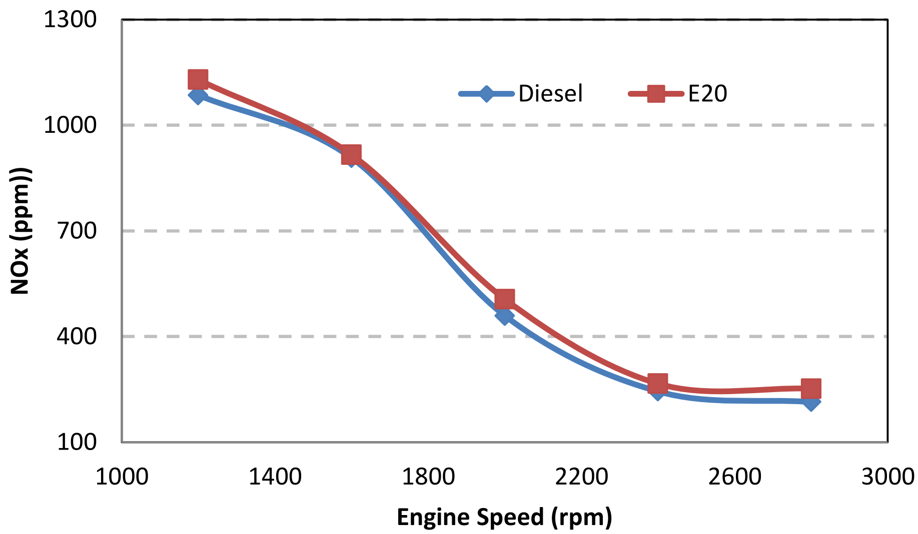

Figure 5: *Nitrogen oxides vs engine speed*

Figure 6 demonstrated that energy efficiencies versus engine speed. As seen from the figure that, energy (thermal) efficiency of both fuels first increasing and decreasing after a certain point. This maximum engine speed point approximately corresponds to maximum torque engine speed point. Decrement of efficiency after a certain point can be explained by mechanical friction in the engine at higher engine speed. Another reason is reduced time for combustion as engine speed increases (Kul and Kahraman, 2016). There is 2.11% average reduction in energy efficiency when ethanol blended diesel fuel used with respect to diesel fuel. The reason can be explained by having lower calorific value of E20.

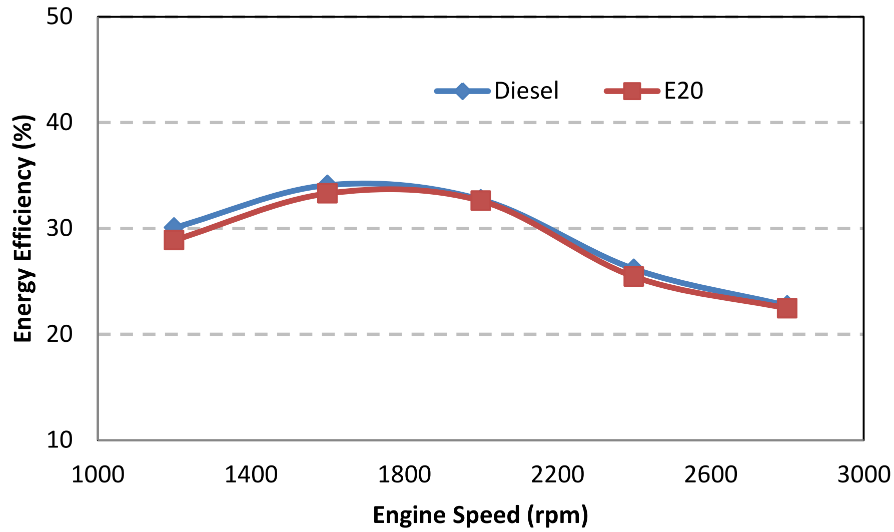

Figure 6: *Energy efficiencies vs engine speed*

Figure 7 showed exergy efficiency with respect to engine speed. Similar trend in exergy efficiency graph was obtained as energy efficiency graph. Exergy efficiency values are lower than energy efficiency values. E20 fuel decreased exergy efficiency by 2.89% according to diesel fuel. As seen from the Figures 6 and 7, exergy efficiency analysis gives more reliable results. It means that, according to energy analysis, results can be found higher although theoretical maximum values to reach are lower.

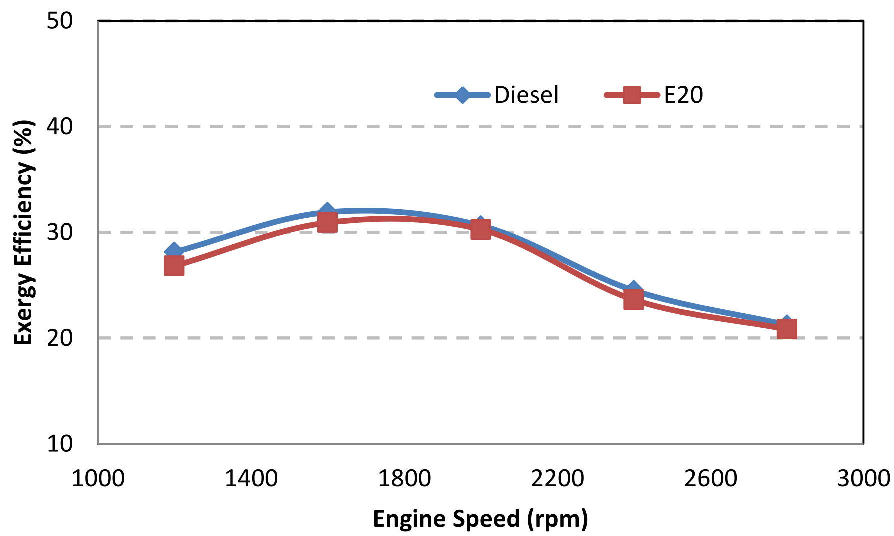

Figure 7: *Exergy efficiencies vs engine speed*

4. Conclusions

In this study a compression ignition engine was fueled with pure diesel and diesel-ethanol blend (80% diesel, 20% ethanol). According to performance results, reductions in torque (5.01%) and power (5.44%), increase on specific fuel consumption (12.56%) were obtained. On the emission basis, decrement in CO (3.34%) and increase on NOx (5.5%) were obtained. When alcohol was added to diesel fuel both energy and exergy efficiency values were decreased (2.11% and 2.89%). On the other hand, exergy efficiency graph gives more accurate and reliable results than energy efficiency graph.

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