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THE EFFECTS OF USING 2-BUTANOL-DIESEL FUEL MIXTURE ON A COMPRESSION IGNITION ENGINE AT DIFFERENT INJECTOR SPRAYING PRESSURES

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Abstract

The basic theme of this study is to improving the diesel engine emissions. For this purpose, 2-butanol is volumetrically added into diesel fuel and the injector spraying pressures were changed. Four stroke single cylinder compressions ignited direct injection engine experimentally tested with a DC dynamometer. 2-Butanol-Diesel fuel mixture prepared with adding volumetrically 3%, 5%, 8% and 10% of 2-butanol into the standard diesel fuel. Injector injection pressure was arranged as 180 bar, 200 bar (original), 220 bar and the results are illustrated in graphics. Contrary to decrease in Egzoz Gas Temperature, NOx and CO_2, while the lower injection pressure was used Brake Specific Fuel Consumption, CO and HC emissions were increased. Running engine with higher injection pressure was also shows the little increase in the Brake Specific Fuel Consumption, CO and HC. All experimental results illustrate the comparison with engine standard running conditions.

Key Words: Alternative fuel; 2-Butanol; Engine performance; Exhaust emissions

1. Introduction

Petrol fuels which are the most widely used fossil fuels of today's internal combustion engine produce many harmful emissions which pollutes atmosphere. These harmful by products of fossil fuel combustion are mainly; CO, CO_2, HC, SOx, NOx and particulate emissions. Studies made on big cities show that a half of the harmful emissions in the atmosphere comes from the exhaust emissions of the internal combustion engines (Şen and Şahin 1996; Sharma and Khara 2001)

Legal regulations brought into power throughout the world in recent years have forced the researchers to study on reducing the emissions. These studies have introduced some changes in design of engine and supplementary systems which are quite successful in reducing emissions to some extent. However the high cost of these innovations currently limits their use. Instead, some alternative fuels which produce less harmful emissions attract a growing attention in recent years (Can Et al. 2005; Kaplan Et al. 2009).

LPG, natural gas, plant derivative fuels (biodiesel) and alcohols (methanol, ethanol, and butanol) are well-known alternative fuels to be used in internal combustion engines directly or to be added to the conventional petrol fuels at certain fractions (Gümüş 2009; Yücesu Et al. 2006; Ciniviz Et al. 2001). Alcohol fuels which are derived from biomass can be obtained from waste vegetables and renewable biological resources (Smith, and Workman 2004; Baştançelik 2006). Alcohol can be produced from starchy agricultural plants and their wastes such as; barley, potato, rice, and sugar cane (Mortimer 1999; Öğüt and Oğuz 2006). That's the reason why alcohol is widely used in America and Brazils which are agriculture country (Öğüt and Oğuz 2006; Solomons 1996). There are some other plants and fruits that can be used to produce alcohol such as; potato, rice, rye, grape and blackberry (Solomons 1996; Mortimer 1992; Kaplan Et al.2009).
Alcohols which are colorless and have an intense odor are defined by the general formula, $C_nH_{2n+2}O$. Alcohols can be used in diesel engines by adding to conventional diesel fuel as fractions. Methanol (CH_3OH), ethanol (C_2H_5OH) and butanol (C_4H_9OH) are the types of alcohol that can be used in diesel

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engines (Bilgin Et al 2002). Alcohols involve oxygen and have a smaller molecular structure than diesel fuel. They don't have sulfur, carcinogenic matters and heavy metals that all have positive effects on the exhaust emissions (Rakopoulos Et al. 2010; Can Et al. 2004). Along with the benefits of alcohols, there are some disadvantages of them as a fuel. One of the major disadvantages of them is the water content of alcohols which causes corrosion in the cylinder and deteriorates the plastic parts of fuel system.

Butanol, which is a type of alcohol, can be produced by the fermentation of agricultural wastes (Shenghua 2007). Butanol involves less water than the other types of alcohols (ethanol, methanol), has a higher heating value and stoichiometric air/fuel ratio (AFR) which makes it a better alcohol to be used in diesel engines.

There are few studies on the effects of butanol addition to diesel fuel on the performance and exhaust emissions of the diesel engines. Al-Hasan and Al Momany added iso-butanol to diesel fuel by 10%, 20%, 30%, and 40% by volume, and tested different load and speed characteristics of a four cylinder four stroke diesel engine (Al-Hasan and Al-Momany 2008). Their study showed that adding iso-butanol to the diesel fuel decreased the engine torque, power, exhaust temperature and thermal efficiency of the engine, while the specific fuel consumption increased. Karabektaş and Hoşöz investigated the effects of iso-butanol addition to the diesel fuel by 5%, 10%, 15%, and 20% by volume on the performance and exhaust emissions of a single cylinder four stroke diesel engine at engine speeds from 1200 to 2600 1/min with 200 1/min increments (Karabektaş and Hoşsöz 2009). They report that adding iso-butanol to diesel fuel decreases the engine torque, power, and exhaust gas temperature and increases the BSFC of the engine. Besides, adding iso-butanol to diesel fuel increased HC emissions while decreasing NOx and CO emissions. Özer in his Master of Science Thesis, added 2-butanol to the diesel fuel by 3%, 5%, 8%, and 10% and investigated the effects of this addition on the performance and emissions of a diesel engine and reported that 2-butanol addition decreased the engine torque, power and exhaust temperature, and increased the BSFC of the engine (Özer 2010). It also increased the HC and CO_2 emissions and decreased NO_x, smoke, and CO emissions. Rakopoulos et al. investigated the effects of n-butanol addition to diesel fuel by 8% and 16% by volume on a six cylinder Mercedes Benz diesel bus engine on the performance and exhaust emissions of the engine at 1200 and 1500 1/min engine speed and various loads (Rakopoulos Et al 2010a). They reported that the addition of n-butanol to the diesel fuel decreased NO_x, CO, and smoke emissions. They reported a significant increase in BSFC and an insignificant increase in thermal efficiency and a decrease in engine torque and power. Rakopoulos et al. tested a single cylinder four stroke direct injection compression ignition engine with different blends of n-butanol and diesel fuel with n-butanol volumetric fractions of 8%, 16% and 24% and investigated the effects of these blends on the engine performance and emissions at three different engine loads and constant engine speed of 2000 l/min. n-butanol addition to the diesel fuel decreased NO_x and CO while increasing the HC emission. The addition of n-butanol also increased the BSFC, decreased the exhaust gas temperature, and slightly increased the thermal efficiency (Rakopoulos Et al 2010b).

During the design and manufacture stages of the engine, there are some measures taken related to the processes before, during and after the combustion in order to decrease the harmful exhaust emissions of diesel engines. The structure of the fuel injection system of a diesel engine i.e. the injection flow rate, injection timing and injector opening pressure (injection pressure) affects the amount of pollutant emissions significantly. There are many studies on the effects of injection pressure on the engine emissions. İlkılıç investigated the effects of three different injection pressures on the emissions of a four cylinder four stroke diesel engine running at ¾ load and various engine speeds. He reported some improvements in CO, CO_2 and NO_x emissions. Sayın et al. investigated ethanol-diesel fuel blends for its performance and emission effects to a single cylinder compression ignition engine at three different injection pressures and injection timings (Sayın Et al. 2009). They reported that changing the injection pressure worsened the emissions. Kulakoğlu, in his Master of Science thesis, investigated the effects of methanol-diesel fuel blends at different injection pressures on the performance and emissions. This study reports that decreasing the injection pressure worsens the performance and emissions less than increasing the injection pressure.

In this study, the effects of adding 2-butanol to the diesel fuel on the engine performance and emissions were investigated with different injection pressure.

2. Material and Method

Experimental setup consists of compression-ignition engine, DC type dynamometer, Exhaust Gas Analyzer, K-type thermocouple to measure the exhaust gas temperature and fuel consumption measurement assembly.

Table 1. Measuring ranges of the measurement tools and uncertainties in the calculated results.

Measurements	Accuracies
Load	±0,6% N
Weigh-arm	±0,1% m
Velocity	±1 1/min
Time	±1% s
Heat	±1 ^oC
CO (%vol)	±0,06%
CO_2 (%vol)	±0,5%
NOx (ppm)	±0,05%
HC (ppm)	±0,12%
The calculated results	Uncertainty
Torque	%0,4
Force	%0,4
Specific Fuel Consumption	%0,7

Standard deviation, accuracy and measuring ranges of the engine used in the test were taken from its manufacturer specifications are given in Table 1.

Table 2. The features of the experiment engine.

Model	KATANA
Number of Cylinders	1
Type	Four-cycle, Air-Cooled
Diameter x Stroke	70 x 55
Fuel supply system	Direct injection
Compression ratio	18:1
Injection pressure	20 Mpa
Rated power	1,937 kW (2600 1/min)

Schematic diagram of the experimental setup is given in Figure 1. DC dynamometer used in the test can hold 10 kW of power at 4000 1/min and also can be used to start the engine. General specifications of the test engine are given in Table 2. Moment of the engine is measured by a load-cell. Exhaust emissions were measured by MRU DELTA 1600L exhaust gas analyzer. Fuel consumption was calculated by dividing the amount of 10 ml fuel, observed at a glass bulb, to the period of consumption in seconds.

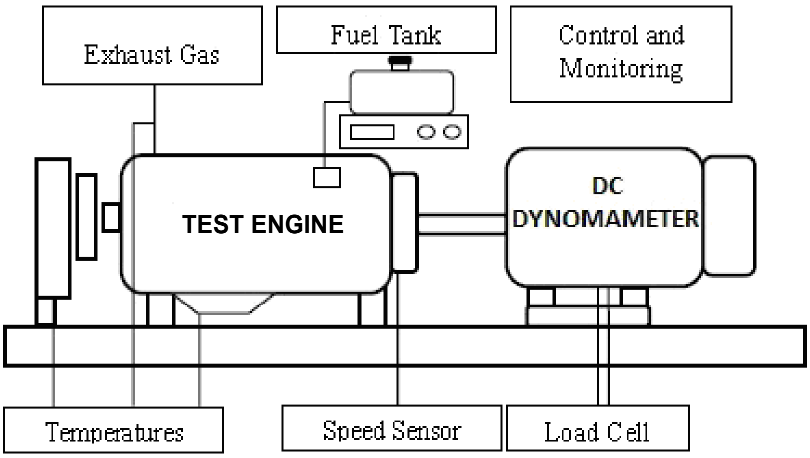

Figure 1. Schematic view of experimental apparatus.

First the engine was tested with standard diesel fuel at standard 200 bar injection pressure. Then 2-butanol was added to diesel fuel by volumetric fractions of 3%, 5%, 8%, and 10% and these fuel blends were tested with different injection pressures at full load and 2600 1/min engine speed at which the maximum engine torque was reached.

Table 3. Diesel and 2-butanol fuel properties (Technical Leaflet 2012, AFDC 2012)

Properties	Diesel	2-butanol
Density (kg/m^3)	0,85	0,81
Boiling point (^{o}C)	190–280	108,1
Heat of vaporization (kJ/kg)	232,6	592
Lower Calorific Value (MJ/kg)	42,6	33
Octane Number	-	94
Cetane Number	42,6	15'lower than
Stoichiometeric air fuel ratio,	14,6	11,1
Molecular weight	193,4	74
Carbon/ Molecular weight Rate	6,8	4,8

The specifications of the fuels used in the experiment were given in Table 3. B0, B3, B5, B8, and B10 symbols in the graphs of the test results stand for Standard diesel fuel, 3% butanol+97% diesel fuel, 5% butanol+95% diesel fuel, 8% butanol+92% diesel fuel, and 10% butanol+90% diesel fuel respectfully.

The engine was allowed to heat up to reach a smooth running stage before each test with each fuel blend begins. Tests were done at injection pressures that are 20 bar higher and lower than the standard 200 bar. Injection pressure is adjusted by changing the thickness of the adjustment shims which affects the tension of the injector spring. By changing these shims, the injector was adjusted to open at 180 bar and 220 bar.

3. Experimental Works and Discussion

Figure 2 gives the BSFC values of 2-butanol-diesel fuel blends according to the different injection pressures. By the addition of butanol to the diesel fuel BSFC increased for all tested fractions. Butanol content of the fuel blend decreases the heating value (Özer 2010; Rakopoulos Et al. 2010). Since the tests were conducted at constant engine speed and load, more fuel had to be injected to the cylinder to compensate the decreasing heating value which means an increased BSFC.

Addition of 2-butanol to diesel fuel decreases the density of the blend. Lower cetane number, viscosity and density decreased by 2-butanol degrade the quality and efficiency of combustion which means that not all of the fuel is converted to work. That's why more fuel needs to be injected into the cylinder to achieve the same power, leading an increase in the BSFC.

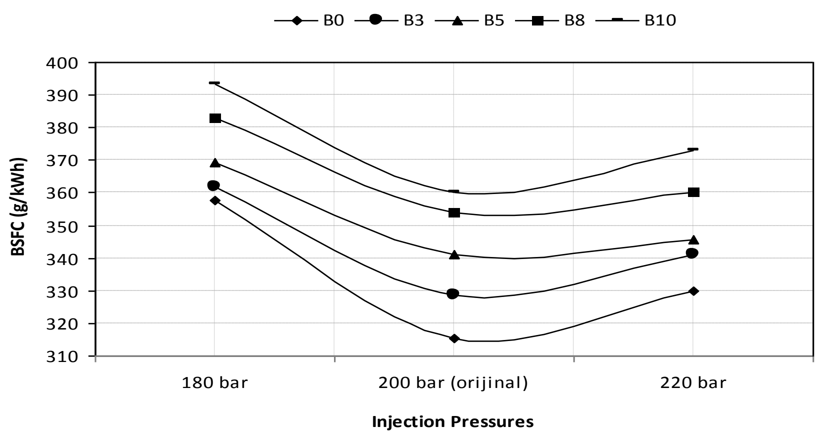

Figure 2. The effect of injection pressure on BSCF.

Since the diffusion depth of injected fuel into the cylinder becomes thinner as the injector pressure decreases, combustion quality becomes poorer and adding 2-butanol to diesel fuel worsens the case and increases BSFC.

Increasing the injection pressure helps the injected fuel to diffuse better and combustion is improved compared to the combustion with 180 bar of injection pressure. However it improves slightly compared to the original injection pressure. This is because the fuel injected with a high pressure can cool the combustion chamber more. Similar results are reported in (Sayın Et al 2009).

Figure 3 gives the variation of exhaust gas temperature by the injection pressure for 2-butanol-diesel blends. Exhaust gas temperature decreased for all fractions of 2-butanol addition compared to the pure diesel fuel. Exhaust gas temperature is an indication of the end-combustion pressure and temperature. Heating value of the blend decreases when 2-butanol was added to the diesel fuel (Al-Hasan and Al-Momany 2008; Karabektaş and Hoşöz 2009). Lower heating value decreases the end-combustion pressure and temperature. Besides, the more the fraction of 2-butanol in the blend is, the lower the cetane number, density and viscosity of the blend. Lower viscosity, density and cetane number cause a poor combustion in the cylinder and decrease end-combustion temperature and pressure as well as the exhaust gas temperature. Decreased injection pressure magnifies the diameter of the fuel particles and prevents fine atomization (Giménez Et al. 2004).

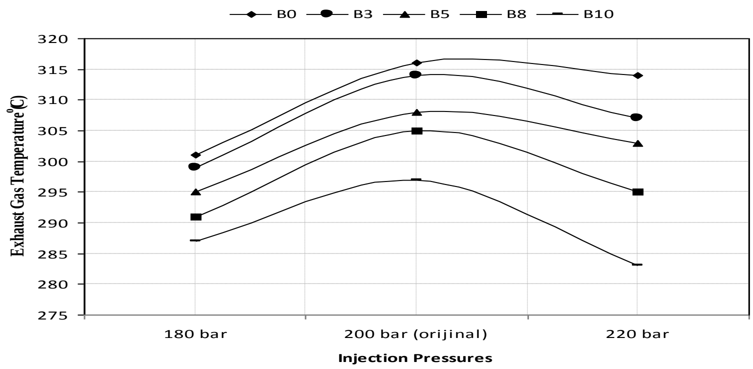

Figure 3. The effect of injection pressure on exhaust gas temperature.

Increased 2-butanol fraction in the blend along with the decreased injection pressure degrades the combustion and decreases the end-combustion temperature. Exhaust gas temperature decreased at 200 bar injection pressure but not as much as it decreased at 180 bar. Increasing injection pressure decreases the diameter of fuel particles and improves the ability of fuel to diffuse into the combustion chamber (Semin and İsmail 2008). Increased atomization ability of diesel and 2-butanol blends absorbs more energy instantly from the air in the combustion chamber to evaporate and thus cools the cylinder and decreases the end-combustion and exhaust gas temperatures.

Figure 4 gives the change of Carbon Monoxide (CO) emissions by the injection pressure for 2-butanol-diesel fuel blends. Although it is known that lack of oxygen is one reason of CO emissions, there are some more parameters that affect CO emission. A CO emission is a good indication of the combustion quality in the cylinders. Since the diesel engines run with high excess air ratio, CO emission is low in diesel engines Szwaja and Naber 2010; Can Et al. 2004; Sayın Et al. 2009).

Addition of 2-butanol which is an alcohol to the diesel fuel decreases CO emissions for all fractions. Adding 2-butanol to diesel fuel decreases the total Carbon (C) number of the blend and therefore decreases the CO emission which is one of the products of combustion. Besides, the oxygen content of butanol improves the combustion and decreases CO emission (Al-Hasan and Al-Momany 2008; Karabektaş and Hoşöz 2009 Sayın Et al. 2009).

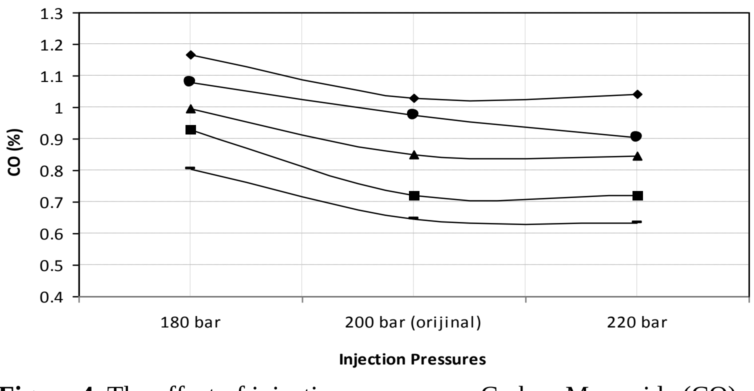

Figure 4. The effect of injection pressure on Carbon Monoxide (CO) emissions.

Figure 4 show that leaner air fuel mixtures caused by the increased injection pressure decreased CO emission which is a byproduct of incomplete burning. Low injection pressures do not mix the fuel with the hot air well that much and there becomes local rich mixture areas in the combustion chamber which leads to partial incomplete burning and CO emission. On the other hand, it is also considered that higher injection pressures provide a better mixture improving the turbulence in the combustion chamber and contributes to the burning process helping to decrease CO emissions.

Figure 5 shows the variation of nitrogen oxide (NOx) emissions of butanol-diesel fuel blends by the injection pressure. Nitrogen oxides are major pollutants in the exhaust gasses of diesel engines. Air fuel ratio, combustion chamber temperature and end-combustion temperature are important parameters affecting the NOx emissions. Increased air fuel ratio slows down the cooling down of cylinder walls and thus the exhaust system stays hot. Instantaneous peak pressures and high end-combustion temperatures over 1800 K increase NOx emissions dramatically (Heywood 1988; İlkılıç 2009).

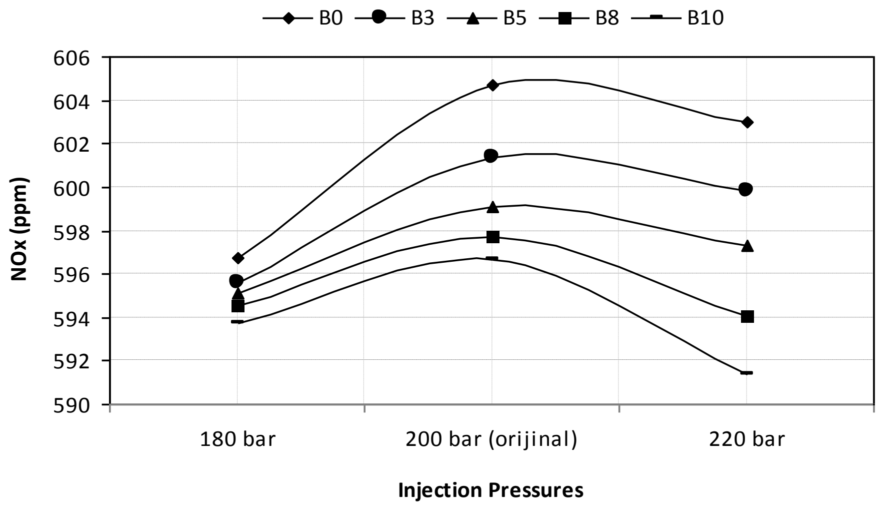

Figure 5. The effect of injection pressure on nitrogen oxide (NOx) emissions.

Figure 5 shows that addition of 2-butanol to the standard diesel fuel decreases NOx emission. 2-butanol decreases the heating value, cetane number and viscosity of the blend. Lower cetane number increases the ignition delay and degrades the combustion. Low heating value of the blend decreases the end-combustion temperature (Al-Hasan and Al-Momany 2008). Lower viscosity affects the diameter of the fuel particles injected into the cylinder. A smaller diameter prevents the fuel from mixing with the air completely and degrades the combustion (Sayın Et al. 2009). Exhaust gas temperature is an indication of the end-combustion temperature.

Injection pressure affects the distribution pattern and the diameter of fuel particles injected into the cylinder (He Et al 2003; Çelikten 2003). Increased injection pressure increases the speed of fuel entering to the combustion chamber from the injector, decreases the diameter of the injected fuel particles as well as the inter-particular distance. Smaller fuel particles diffuse into the air less than the bigger ones due to their low inertia. This shortens the ignition delay and causes the combustion to begin before the fuel is completely distributed to every corner of the combustion chamber. Earlier start of the combustion affects the end-combustion pressure and temperature directly and decreases the NOx emission. As can be seen from the Table 3, evaporation heat of 2-butanol is bigger than diesel fuel. Higher evaporation heat of 2-butanol means that the injected fuel will absorb more heat from the air and will cool the combustion chamber more. This also decreases the end-combustion temperature (Karabektaş and Hoşsöz 2009).

Increasing injection pressure decreases the diameter of the fuel particle and combined with the increased evaporation heat cools down the cylinder fast and decreases the end-combustion temperature. Decreased end-combustion pressure decreases the production of NOx emission. Decreasing the injection pressure magnifies the diameter of injected fuel particles. 2-butanol decreases the density and viscosity and thus decreases the depth of diffusion of injected fuel blend into the air. This situation decreases the end-combustion temperature and consequently the NOx emissions as well.

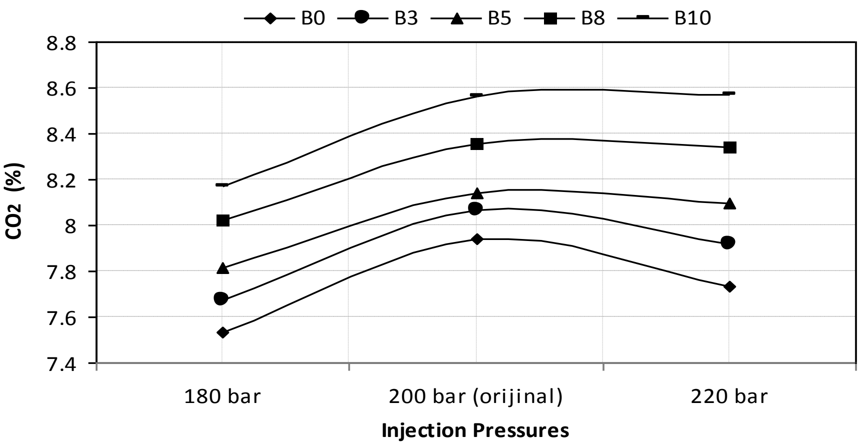

Figure 6. The effect of injection pressure on Carbon dioxide (CO_2) emissions.

Figure 6 gives the variation of CO_2 emission by the injection pressure. Air/fuel ratio significantly affects the CO production of engines and this interaction also affects the amount of CO_2 emission. Maximum CO production decreases CO_2 while a decrease in CO increases the CO_2 emissions as can be seen from the Figure 4 (İlkılıç 2008a; İlkılıç and Yücesu 2008b).

Increasing the 2-butanol fraction in the fuel blend also increased CO_2 emission. Low injection pressures cause non-homogenous mixture of air and fuel which leads to local rich mixture areas in the combustion chamber preventing the complete combustion. High injection pressures, on the other hand, increase turbulence in the cylinder which ensures better mixture resulting complete combustion products.

Figure 7 shows the variation of Hydrocarbon (HC) emissions by the injection pressure of 2-butanol-diesel fuel blends. HC emissions of diesel engine come from the unburnt fuel and burnt engine oil in the exhaust gasses (İlkılıç and Yücesu 2008b; Shenghua Et al. 2008). HC emission increases as the fraction of 2-butanol in the fuel blend is increased. Lower heating value of 2-butanol-diesel fuel blend restricts the complete combustion of the fuel in the cylinder and unburnt fuel is exhausted from the engine. Besides, decreased viscosity and cetane number also negatively affects the combustion process.

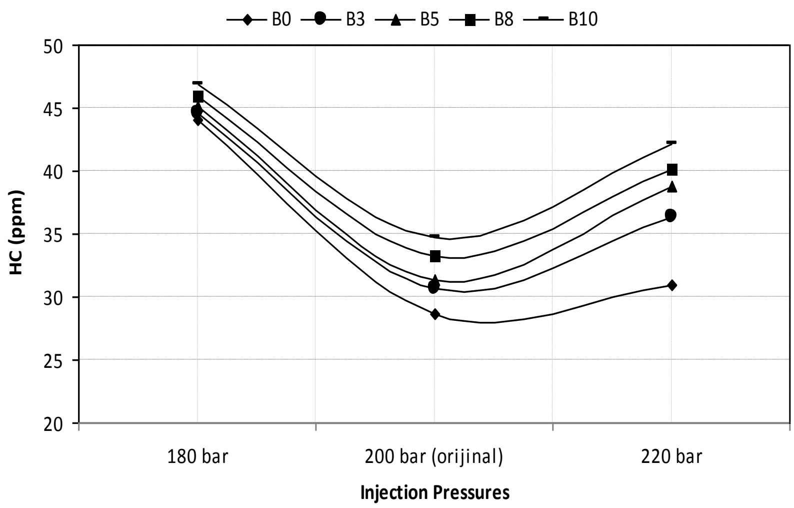

Figure 7. The effect of injection pressure on Hydrocarbon (HC) emissions.

It can be seen from the Figure 7 that decreased injection pressure increase the HC emission significantly. Decreased viscosity along with the low injection pressure shortens the diffusion depth of fuel blend into the air in the cylinder and worsens the combustion further. HC emissions increased at 220 bar injection pressure but not as much as it increased at 180 bar injection pressure. Increased injection pressure makes a better air-fuel mixture and improves combustion decreasing HC emissions however, higher evaporation heat of 2-butanol cools down the cylinder more and increases the amount of unburnt gasses.

4. Results

In this study, the effects of adding butanol to diesel fuel with the volumetric percentage of 3%, 5%, 8%, and 10% on a compression ignition engine were investigated for different injection pressures. Decreased engine torque and increased BSFC caused by the addition of 2-butanol to diesel fuel are compensated to some extent by increasing the injection pressure. At injection pressures below 200 bar which is the original injection pressure, BSFC increased and engine torque decreased. Addition of 2-butanol to diesel fuel increased HC and CO2 emissions while decreasing CO and NOx emissions. CO emissions tend to decrease when the injection pressure is increased from 180 bar towards 220 bar, and 2-butanol fraction in the fuel blend is increased from 3% to 10%. NOx emissions decreased as the 2-butanol fraction and injection pressure are increased. CO_2 emissions remained the same as the original injection pressure when the injection pressure fraction is increased. However, CO_2 emission decreased as the injection pressure decreased. 2-butanol addition to diesel fuel increased HC emissions. Decreasing injection pressure increased HC emissions but increasing the pressure decreased this emission. However, the HC emission of the original engine conditions gives the ideal results.

As it can be understood from the results of this study, emissions and characteristics of an engine can be changed by modifying the fuel properties and injection pressure. Some fuel blends prepared at laboratory conditions along with manual modification of injection pressure produced positive results on some emissions and engine torque. Worldwide restrictions of engine emissions emphasize the fact that injection pressure and fuel properties can be automatically changed to achieve a better emission management of the engine.

Nomenclature

LPG	Liquefied Petroleum Gas	AFR	air/fuel ratio
CO	Carbon monoxide		HC Hydrocarbon
CO_2	Carbon dioxide	NOx	Nitrogen oxide
BSFC	Brake Specific Fuel Consumption	B0	Standard diesel fuel
B3	3% 2-butanol + 97% diesel fuel	B5	5% 2-butanol + 95% diesel fuel
B8	8% 2-butanol + 92% diesel fuel	B10	10% 2- butanol + 90% diesel fuel

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