ENVIRONMENTAL IMPACTS OF BIO-FUELS THROUGH EMISSION

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Summary

Air pollution is emerging to become a global problem. Emission from vehicles is one of the most dangerous polluters. Use of bio-diesel is one of the means to reduce the emissions, particularly of particulate matter (PM) and nitrogen oxides (NO_x). The trend toward using bio-fuel as an alternative fuel will significantly increase in the near future as crude oil resources become depleted. This paper presents experimental results from a heavy-duty diesel engine using different bio-diesel fuels. Experimental bio-diesel fuels are rapeseed methyl ester (RME), blends of RME with conventional diesel fuel, gas to liquids (GTL), blends of GTL with conventional diesel fuel, O_2-diesel fuels called O_2-1 (O_2-diesel) in this experiment (a blend of ethanol and diesel fuel) and the blend of O_2-diesel and 5% RME called O_2-2 (95% O_2-diesel - 5% RME). The results presented here demonstrate that those bio-fuels not only represent a solution to counter the mounting scarcity of fossil fuels but also reduce the central elements of emissions.

1. Introduction

A substance in the air that can be harmful to humans and the environment is known as an air pollutant. Pollutants can be in the form of solid particles, liquid droplets, or gases. In addition, they may be natural or man-made. Exhaust gases from engines primarily contribute to forming air pollutants [1]. Therefore, finding methods which reduce emissions from vehicles to meet more stringent requirements of limiting air pollution are important and urgent tasks for researchers, manufacturers and regulators.

Besides technological solutions to reduce emissions from internal combustion engine, bio-fuels and their blend with fossil fuel have been used for a long time as they seem to be the most promising solution to emissions and the depletion of crude oil resources. Bio-fuel counterparts can be bio-gasoline (bio-ethanol), bio-diesel and bio-jet fuel. In practice, ethanol or the blend of ethanol and conventional fuels have usually been used for gasoline engine due to their suitable properties [1]. Therefore, researching the effects of the mixture of diesel fuel and ethanol as oxidised substance is an experimental goal. In this paper, the blend of ethanol and conventional diesel fuel called O_2-diesel (manufactured by Shell) or O_2-1 and the blend of O_2-diesel and 5% RME called O_2-2 are used to experiment because of the increasing trend of using diesel vehicles in transportation. In our experiments, the use of other bio-diesel such as RME (B100), the blend of RME and diesel fuel (10% RME - B10, 50% RME - B50), GTL (G100) and the blend of GTL and diesel fuel (50% GTL-G50) are also studied. Experiments have also been carried out at different operating parameters such as full load, part load of engine and different EGR ratios (Exhaust Gas Recirculation - Exhaust gas is recirculated into the intake manifold of engine to reduce maximum flame temperature in the combustion chamber) to generally and deeply analyse the emission of bio-diesel.

2. Emission and environmental and social health effects

The combustion of fuels with air containing O_2, inert gases and N_2 releases energy as heat in an exothermic reaction [1]. The heat released in internal combustion engine by hydrocarbon-based fuels such as gasoline and diesel fuel is determined by numerous incomplete reactions dependent on the compositions of the hydrocarbons in the fuel. Diesel fuel is composed of about 75% saturated hydrocarbons (primarily paraffins including *n*, *iso*, and cycloparaffins), and 25% aromatic hydrocarbons (including naphthalenes and alkylbenzenes) [1, 2]. Besides the main components such as CO_2, water vapourvapour and N_2, pollutants such as carbon monoxide, unburned and partly burned hydrocarbons (HC-aldehydes, ketones, etc.) and NO_x also exist in exhaust gas of a diesel engine. These pollutants must follow national and international regulations. Pollutants are primarily produced by an interruption of the reaction chain when its dwell time in the combustion chamber is short. Hence, the equilibrium no longer exists. Inhomogeneities in the mixture caused by different air-fuel ratios (λ), combustion chamber wall effects and impurities and additives in the fuel also contribute to undesired by-products. Depending on the type of the fuel and combustion process, solids may also be present as particle emissions. Unrestricted exhaust components produced by the thermal cracking of hydrocarbons and its by-products are increasingly attracting attention since they either are potentially hazardous or cause a discernible odour [3].

2.1. Nitrogen oxides (NO_x)

Unlike CO and hydrocarbon, NO_x, which consists of nitrogen monoxide (NO) and nitrogen dioxide (NO_2), is a product of complete combustion. Nitrogen monoxide is the predominant nitrogen oxide produced inside an engine cylinder. The principal source of NO is the oxidation of atmospheric (molecular) nitrogen. However, if the fuel contains a significant amount of nitrogen, the oxidation of the fuel compounds containing nitrogen is an additional source of NO. It is generally accepted that the following are the principal reactions in the combustion of near stoichiometric fuel-air mixtures. Often called the extended Zeldovich mechanism, these reactions govern the formation (and destruction) of NO from molecular nitrogen [1]:

$$O + N_2 \rightarrow NO + N$$

$$N + O_2 \rightarrow NO + O$$

$$N + OH \rightarrow NO + H$$

NO forms in both the flame front and post-flame gases. However, since combustion in engines occurs at high pressure, the flame reaction zone is extremely narrow (≈ 0.1mm) and the residence time within the zone is brief. Also, due to the cylinder pressures that increase during the combustion process the gases are compressed to a temperature higher than immediately after combustion. Thus, NO formation in the post-flame gases almost always dominates any formation of NO in the flame-front. Furthermore, the NO formation rate is a function of the gas temperature and fuel-air equivalence ratio in post-flame gases. In an engine, a noteworthy NO level can first be detected above around 1,900°C [1]. Overall, more than 90% of NO_x emissions are nitrogen monoxide. Fuel nitrogen is also a source of NO by means of a different and not yet fully explained mechanism. The nitrogen in distillate fuels can exist as amines and ring compounds (e.g. pyridines, quinolines and carbazoles). During combustion, these compounds are likely to undergo some thermal decomposition prior to entering the combustion zone. Therefore, the precursors of NO formation are nitrogen-containing compounds with low molecular weights such as NH_3, HCN and CN. Detailed information on the kinetics of NO formation from these compounds is limited. A characteristic of NO is its reactivity with oxygen and particularly quick reactivity with ozone to form NO_2. Pure NO does not irritate the lungs but if NO_2 remains unconverted, methemoglobin forms after resorbed by the respiratory tract. NO is an endogenous modulator of blood vessel tone and thus a well studied substance in terms of physiology and metabolism [1].

NO_2 has a pungent odour and a reddish brown color. A plausible mechanism for the persistence of NO_2 is:

$$NO + HO_2 \rightarrow NO_2 + OH$$

Chemical equilibrium considerations indicate that NO_2/NO ratios should be negligibly small and NO_2 can be 10% of total exhaust of nitrogen oxides emissions [1, 2]. As a free radical, NO_2 is basically in a position to abstract hydrogen from fatty acids and thus to cause lipid peroxidation, which ultimately leads to a loss of function in biological membranes. In the presence of water, NO_2 develops as a cellular poison in the respiratory tract, through the nitric acid (HNO_3).

2.2. Hydrocarbon (HC)

Ideally, an internal combustion engine's combustion process corresponds to the following reaction [1]:

$$C_n H_m + (n + \frac{m}{4})\ O_2 \rightarrow n\ CO_2 + \frac{m}{2} H_2O$$

In practice, the combustion process does not produce carbon dioxide and water alone. Thus, combustion in an internal combustion engine is usually an incomplete process. As a result, incomplete combustion of the hydrocarbon-based fuel results in hydrocarbons or more organic emissions. The level of unburned hydrocarbon in the exhaust gases is generally specified in term of the total hydrocarbon concentration expressed in parts per million. Engine exhaust gases contain a wide variety of hydrocarbon compounds. Diesel fuel contains hydrocarbon compounds with higher boiling points and hence higher molecular weights than gasoline [1, 2]. Also, substantial pyrolysis of fuel compounds occurs within the fuel sprays during the diesel combustion process. Thus, the composition of the unburned and partly oxidised hydrocarbons in the diesel exhaust is much more complex than in the spark-ignition engine and extends over a larger molecular size range. Hydrocarbon constituents range from methane to the heaviest hydrocarbons that remain in the vapour phase in the heated sampling line (which is usually maintained at about 190°C) [2]. The levels of hydrocarbon emission from diesel engines vary widely depending on operating conditions.

So far it has not been easy to assess the direct impact of hydrocarbon emissions on humans. Hydrocarbon emissions are sometimes slightly relevant toxicologically (alkanes or alkenes etc.) and can also be carcinogenic (benzene) [2]. Hydrocarbons from engine emissions contribute to the development of summer smog.

2.3. Soot

Soot particles form primarily from the carbon in the diesel fuel and the incomplete combustion [1].

$$C_n H_{2n+2} + (n+1)O_2 \rightarrow nC + (n+1)H_2O$$

The formation process begins with a fuel molecule containing 12 - 22 carbon atoms and having an H/C ratio of about 2 and ends with particles that are typically a few hundred nanometres in diameter, composed of spherules with 20 - 30nm in diameters, each of which contains some 10^5 carbon atoms and has an H/C ratio of about 0.1. Soot forms in the diesel combustion environment at temperatures between around 1,000 and 2,800K, at pressures of 50 - 100 bar and with sufficient air to fully burn all the fuel [2]. Solid soot particles form from a fraction of the fuel in milliseconds. Soot formation occurs in two stages. In the first stage, particles form. The initial condensed phase material is produced by the fuel molecules by means of oxidation and pyrolysis products. These products typically include various unsaturated hydrocarbons, particularly acetylene's higher analogues ($C_{2n}H_2$) and polycyclic aromatic hydrocarbons (PAH). These two types of molecules are considered the most likely precursors of soot in flames. In the second stage, particles grow. This involves surface growth, coagulation and aggregation. Surface growth, which generates the bulk of the solid-phase material, involves the attachment of gas-phase species to the surface of the particles and their incorporation into the particulate phase [2]. Surface growth reactions lead to an increase in the amount of soot but the number of particles remains unchanged. These stages of particle generation and growth constitute the soot formation process. In each stage, oxidation can occur, during which soot or soot precursors are burned with oxidising species to form gaseous products such as CO and CO_2. The real emission of soot from the engine will depend on the balance between these processes of formation and burnout [1, 2].

2.4. Particulate matter (PM)

Diesel particulates primarily consist of carbonaceous material (soot) generated in combustion, which have absorbed some organic compounds [1]. Most particulate material results from incomplete combustion of fuel hydrocarbons, but also from the lubricating oil. Other sources are hydrocarbon compounds (some of which are bound to soot) and a few sulfates in the form of aerosols. In a combustion engine, the development of particles is related to the development of soot, which in turn basically depends on the local temperature of the zone the fuel enters and a low oxygen supply. According to the Acetylene Theory, the combustion of different hydrocarbons runs through several intermediate substages such as cracking and dehydration. This increases the share of carbon molecules until the first particle with a diameter larger than 0.01μm develops, around which so-called primary particles coagulate to form larger units with diameters from 0.01 - 0.08μm (forming secondary particles). Their large specific surfaces enable uncombusted and partly combusted hydrocarbons, especially aldehydes, to bond to the secondary particles. When combustion occurs, the secondary formation phase is soot reoxidation governed by the dwell time and oxygen concentration. A specific problem of diesel engines is the conflict between particles and NO_X. The conditions for low particle formation and low hydrocarbon emissions (achieved with higher temperatures) conflict with the preconditions for low nitrogen oxide emissions. Therefore, attention is concentrated on the secondary formation phase of soot reoxidation. Soot reoxidation necessitates a large amount of mixture formation energy in the last phase of combustion. This can be attained by a specific swirl and tumble in the combustion chamber, higher injection pressure and a faster injection rate at the end of the injection process. Unfortunately, these conditions are prerequisites to high NO_X emissions.

Numerous environmental studies have concluded that increases of particle concentration in the air correlate with increases in the number of patients with respiratory and circulatory illnesses. Also found is a link between the risk of lung cancer and particles as well as ozone and sulfur dioxide. In general, particle emissions have a negative impact on human health, especially in particularly sensitive individuals, e.g. children, the elderly and invalids.

2.5. Carbon monoxide (CO)

Carbon monoxide is likewise a product of an incomplete combustion process. CO emissions from internal combustion engines are primarily controlled by the air fuel ratio. CO concentrations in the exhaust of fuel-rich mixtures steadily increase as the air fuel ratio decreases, i.e. as the amount of excess fuel increases. Since the fuel-air mixture must be enriched when an engine is cold, CO emissions during engine warm-up are much higher than emissions in the fully warmed-up state.

Carbon monoxide is a colourless and odourless gas and attaches itself to hemoglobin 250 times more strongly than oxygen. As CO concentrations increase in inhaled air, the suppression of oxygen induces symptoms from suffocation to death. Acute poisoning occurs above 2,000ppm. All in all, CO emissions from internal combustion diesel engines are insignificant [1, 3].

2.6. Unregulated emission components

Important unregulated exhaust gas components in untreated exhaust from diesel engines are cyanide, ammonia (NH_3), sulfur dioxide (SO_2) and sulfates. Of the specific hydrocarbons, methane, ethane, ethene, ethine, benzene and toluene are of particular interest. Of the PAH, phenanthrene, pyrene, fluorene, fluoranthene and anthracene predominate and in that order. The concentration of these components is at least six times higher than that of other individual PAH substances and forms about 90% of the PAH [3]. The components cited are formed from trace substances in the fuel, in the lubricant and, to a degree, from secondary reactions in the exhaust system.

Combustion exhaust gases contain a multiplicity of different toxic elements. The bulk of the over 150 PAH substances identified are mutagenic and carcinogenic. Many studies have been carried out on the influences of diesel engine emissions on the health of humans and the environment [2, 3]. In 1978, an Ames Test (Salmonella Microsome Test) performed by Huisingh demonstrated for the first time the capability of diesel engine emissions to cause genetic damage. Since then, many further studies have confirmed these findings [3].

In this paper, main emissions from diesel engine such as hydrocarbon, NO_x, PM (illustrated through soot or FSN- Filter Smoke Number) with different biofuels and the blends have been evaluated. FSN have been measured at full load with different speeds (from 600rpm-idle to 2,400rpm-maximum speed). In addition, FSN and other emissions such as hydrocarbon and NO_x have been tested at part loads (1,100rpm - 213Nm and 425Nm), full load (1,400rpm - 850Nm) with different EGR (Exhaust Gas Recirculation- the effective method to reduce NO_x emission in diesel engine) ratios (0%, 9% and 27%).

Table 1. *Properties of O_2-diesel (ethanol-diesel blend) [5]*

Parameters	Testing procedure	Unit	DIN EN 590	Diesel fuel (DF)	O_2-diesel
Heat value	DIN 51 900-2	MJ/kg	approx. 42	43.866	42.360
Cetane number	DIN EN ISO 5165		min. 51	55.5	54.8
Cetane index	DIN EN ISO 5165		min. 46	54.6	52.8
Density in 15°C	EN ISO 12185	g/cm^3	0.820 - 0.845	0.8276	0.8252
PAK	DIN EN 12916	% (m/m)	max. 11	2.0	1.9
Sulfur content	EN DIN 51400-10	mg/kg	max. 10	8	3
Flash point	DIN EN 22719	°C	> 55	56.9	12.9
Coke residue (of 10% distillation residue)	DIN EN ISO 10370	% (m/m)	max. 0.30	0.004	0.08
Water content	EN ISO 12937	mg/kg	max. 200	130	250
Oxide ash	DIN EN ISO 6245	% (m/m)	max. 0.01	0.001	0.004
Total contamination	DIN EN 12662	mg/kg	max. 24	27.3	27.8
Copper corrosion (3 hours at 50°C)	EN ISO 2160		1	1	1
HFFR Lubricity with 60°C	DIN EN ISO 12165-1	µm	max. 460	317	284
Viscosity in 40°C	DIN 53015	mm^2/s	2.00 - 4.50	2.71	2.03
Distillation % [V/V] - 250°C % [V/V] - 250°C 95% - Point	DIN EN ISO 3405	 Vol. -% Vol. -% °C	 < 65 min. 85 max. 360	 41 94 352.9	 45 95 353.3
Fatty acid methyl ester content	EN 14078	% (V/V)	max. 5	0.17	0.16
Cold filter plugging point (CFPP)	DIN EN 116	°C	max.0	-8	-7

3. Experimental bio-diesel

3.1. O_2-diesel (Ethanol diesel fuel) or O_2 -1(as called in this experiment)

O_2-diesel that is used in this study is supplied by Shell Company. The analysis of O_2-diesel used for the experiments in this study was performed at the University of Rostock. Table 1 presents the properties of experimental O_2-diesel.

O_2-diesel fuel is a mixture that consists of the following components [5]:

Water-free ethanol: 7.7% Vol.

Diesel fuel: 91.6% Vol.

Additive 2EHN: 0.2% Vol.

Additive O2DO5: 0.5% Vol.

The additive 2EHN with 0.2% Vol. was used to enhance the cetane number for a number of reasons. One of them is that a small amount of water can be introduced into the fuel system because ethanol has an affinity to water (the experimental ethanol diesel blend had a water content of less than 0.5%) and because blend levels of up to 15% are often desired. One way to achieve this is to use additives. Two common types of additives are surfactants and co-solvents. O_2-diesel with these additives are very stable. Co-solvents have an immediate polarity between ethanol and diesel fuel and act as a bridging agent to produce a homogeneous blend.

Experiments were carried out with O_2-1 and the blend of O_2-diesel and 5% RME (called as O_2-2 in this experiment).

3.2. Rapeseed methyl ester (RME)

RME is manufactured from rapeseed. RME has been used as bio-diesel fuel in Europe for a long time. Since the 2,000s, diesel fuel, including 5% bio-diesel (RME), is used in practice [4]. Therefore, experiments are being conducted with different blending ratios of diesel fuel and RME, for example 100% RME, B50 (50% RME), B10 (10% RME). Table 2 show the properties of experimental RME.

Table 2. *Properties of RME [5]*

Parameters	Testing procedure	Unit	Diesel fuel	RME
Heat value	DIN 51606	MJ/kg	43.866	37.6
Cetane number	DIN EN ISO 5165		55.5	45 - 59
Density at 15°C	ISO 3675	g/cm^3	0.8276	0.875 - 0.900
Sulfur content	ISO 4260	mg/kg	8	9 - 12
Flash point	ISO 2719	°C	56.9	110
Coke residue (of 10% distillation residue)	DIN EN ISO 10370	%	0.004	0.05
Water content	DIN 51606	mg/kg	130	300
Oxide ash	DIN EN ISO 6245	%mass	0.001	0.01
Total contamination	DIN EN 51419	mg/kg	27.3	20
Copper corrosion (3 hours at 50°C)	EN ISO 2160		1	1
Viscosity at 40°C	ISO 3104	mm^2/s	2.71	3.5 - 5
Cold filter plugging point (CFPP)	DIN EN 116	°C	-8	-9 to -7

Table 3. *Properties of GTL [5]*

Parameters	Testing procedure	Unit	Results
Density	EN ISO 12185	g/cm^3	0.7853
Viscosity at 40°C	DIN EN ISO 3104	mm^2/s	3.5871
Cloud point	DIN EN 23015	°C	0
Cold filter plugging point (CFPP)	DIN EN 116	°C	-3
Sulfur content	DIN 51400 T11	mg/kg	< 5
Heat value	ASTM D240	MJ/kg	44,398
Cetane number			74
Distillation	DIN EN ISO 3405		
Boiling point		°C	202.3
T10		°C	244.7
T50		°C	295.2
T90		°C	340.9
Boiling end point		°C	351.3
Residue		% v/v	2.0
Flash point	ASTM D93	°C	89
Carbon to hydrogen ratio			2.13
Aromatics	ASTM D5186	mass %	1.4
Gum content	ASTM D381	mg/100ml	5.9
Ash	ASTM D482	mass %	< 0.001
Carbon residue	ASTM D524	mass %	0.03

3.3. Gas to liquids (GTL)

Produced by the Shell Middle Distillate Synthesis (SMDS), GTL is one of the new alternative fuels used for diesel engines without any modifications. The Lab of Shell Global Solutions (Deutschland) GmbH in Hamburg performed the testing of the GTL properties. Table 3 presents the test results.

Experiments are conducted with different blending ratios of diesel fuel and GTL, for example 100% GTL, G50 (50% GTL).

4. Effects of bio-diesel and these blends on emission

Research was carried out on a DEUTZ BF6M 1013 EC heavy-duty engine with different operating points. The DEUTZ BF6M 1013 EC is a four-stroke direct injection engine with six in-line cylinders and turbocharger and are retrofitted with exhaust gas regulations (EURO II). Experiments have been carried out in the laboratory of the Institute of Mobile Systems, University of Magdeburg, Germany. Experiments have also been conducted at the different operating points of engine such as full load, part load and different EGR ratios.

At full load of engine, diesel fuel, $O_2$1, B10 (10% RME - 90% DF), B50 (50% RME - 50% DF), B100 (100% RME) and GTL (G100) were tested. At other operating points of the engine, diesel fuel, O_2-1, O_2-2, B10, B50, B100 (RME) were G50 (50% GTL-50% DF), G100 were experimentally examined.

Besides the different operating points, experiments were also carried out at different EGR (Exhaust Gas Recirculation) ratios. EGR is the effective method to reduce NO_x emission in diesel engine. EGR has not been analysed in detail in this paper.

4.1. FSN

Bio-diesel and their blends point to better emissions trends, especially the FSN at full load (Fig.1). The FSN decreases by roughly 40% with B100 and at least 21% with O_2-diesel and B10. The FSN falls around 38% with B50. GTL 100% has a lower FSN than O_2-diesel, except at speeds above 1,800rpm. Compared with diesel fuel, GTL 100% decreases by about 6.4% in the minimum point (2,200rpm) and around 22% in the maximum point (800rpm). All the alternative fuels and their blends have generally been found to decrease the FSN.

Experimental results also confirmed that fuel temperatures had less impact on engine torque and fuel consumption (B_o g/h) when RME, G100 and diesel fuel were used than when O_2-diesel was used. The temperatures of RME, GTL and conventional diesel fuel were similar under most operating points and conditions. By contrast, the temperature of O_2-diesel significantly influences engine torque and fuel consumption. Experimental results indicate the engine runs unstably when the temperature of O_2-diesel is around 55°C (the same working temperature as diesel fuel, GTL and RME). When the temperature increased from around 30 - 55°C, engine torque changed approximately 10% and B_o approximately 8.3%. The evaporation of ethanol in O_2-diesel and its lower boiling temperature range are responsible for these effects. Experimental results also confirmed the engine ran stably when the temperature of O_2-diesel was approximately 30°C. Therefore, this was the temperature maintained in experiments with O_2-diesel.

Fig.2 presents decreasing trends of FSN for all alternative fuels and different operating modes of engine, compared with diesel fuel, except when the EGR is 27% and except for G100 and G50. The changing percentages are largest with B100 and lowest with GTL, its blend and B10. The maximum changing percentage is over 60% with B100 at lower part load (1,100 1/min - 213Nm). When the speed is the same (1,100 1/min), EGR is 9% and engine load increases from 213 - 425Nm, the changing percentage decreases from over 50% to over 40% with B100 and increases modestly with O_2-diesel.

4.2. NO_x

Compared with diesel fuel, the largest increased percentages are always found with B100 and the strongest decreased percentages usually occur when G100 is used (Fig.3) because RME has the lowest heat value, the highest density, highest injection mass and highest injection pressure not only compared with diesel fuel but also other alternative fuels. Therefore, the combustion rate and combustion temperature peak are highest with RME.

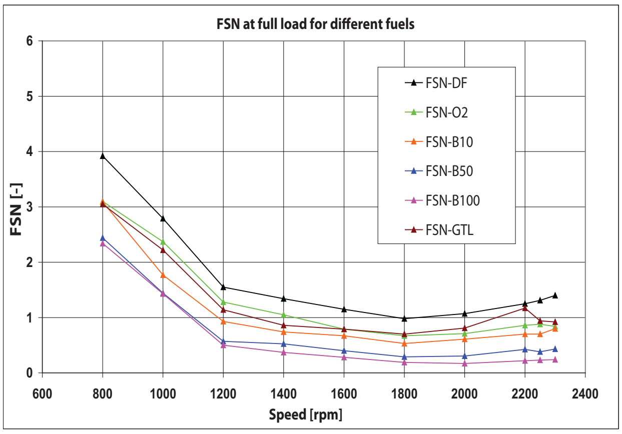

Fig.1. *FSN for different fuels [5]*

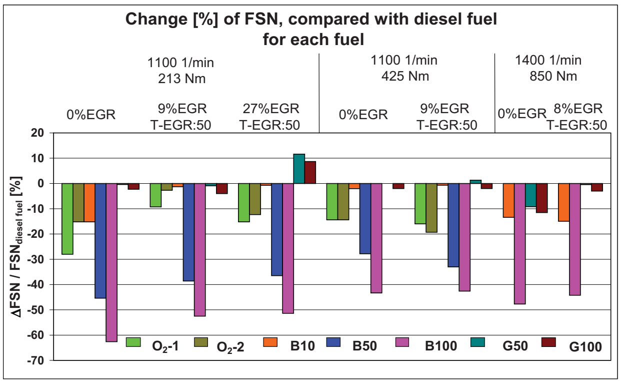

Fig.2. *Change of FSN in percentage, compared with diesel fuel [5]*

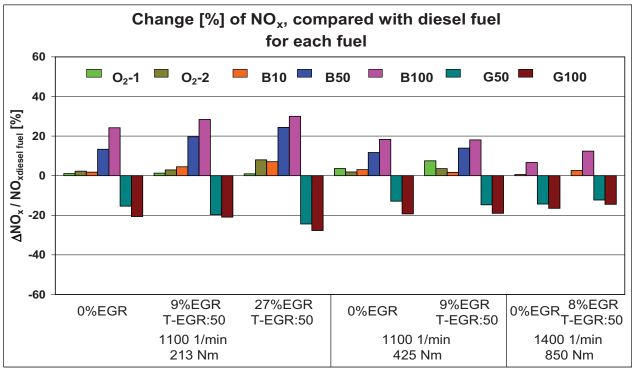

Fig.3. *Change of NOx in percentage, compared with diesel fuel*

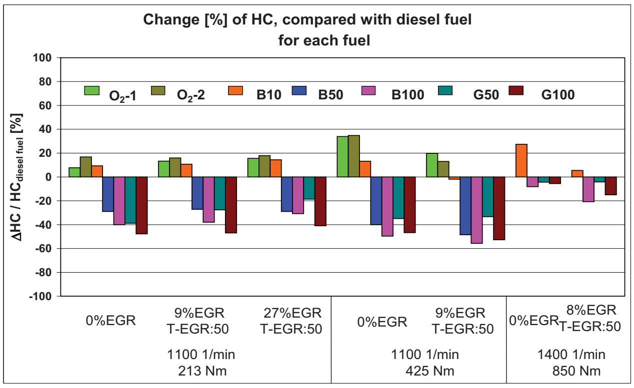

Fig.4. *Change of hydrocarbon in percentage, compared with diesel fuel*

Compared with diesel fuel, the largest increased percentage is over 30% with B100 when EGR is 27%. The strongest decreased percentage is over 20% with G100 under the same conditions (Fig.3). RME blends have lower changing percentages than neat RME and G50 has lower changing percentages than G100. Changing percentages of NO_X emission of different fuels are smaller when engine load increases. When the speed is maintained (1,100 1/min), there is no EGR and the engine load increases from 213 - 425Nm, the changing percentage of NO_X with B100 drops from 24 - 18% and is around 6.7% when the engine runs at maximum torque (1,400 1/min - 850Nm).

Generally, GTL and the blend always present a decreasing trend of NO_X emission. In contrast, other alternative fuels and their blend such as RME and O_2-diesel show an increase of NO_X emission. Therefore, a combination of EGR and bio-fuel is used for reducing NO_X emission in diesel engines.

4.3. Hydrocarbon

Hydrocarbon emission changes significantly with B100, G100 and G50 (Fig.4). Maximum changing percentages (over 50%) occur with B100 and G100 when the EGR ratio is about 9% and the engine runs at higher part load. Compared with diesel fuel, the maximum increased percentages are over 20% (about 8ppm) with B10 at maximum torque and without EGR and over 30% (over 30ppm) with O_2-diesel at higher part load and without EGR.

Like NO_X emission, hydrocarbon also increases when engine runs with GTL and O_2-diesel. Higher increase occurs with higher load of engine.

5. Conclusions

Emissions decrease with most bio-fuels. Changing percentage of emission increases with higher content of bio-fuel that is mixed with conventional fuel. Combination of other methods such as EGR, load, EGR temperatures, and bio-fuels are positive means for decreasing pollutants from the exhaust gas of an diesel engine. This confirmed that use of bio-fuels or the blend of bio-fuels and conventional fuels will meet stricter future requirements for emissions which pollute the environment. The experimental results also confirmed that step-by-step increase of the percentage of bio-fuel in the blend is a suitable practical method in applying progress. Finding and applying bio-fuels will be important future goals for the world. Protecting and encouraging bio-fuel use through tax and other policies will be required for a green planet in the future.

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