

Waste Tyre Oil as Alternative Fuel in CI Engine: A Review

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ABSTRACT

Due to limited energy resources, high energy demand and constrict emission norms led the researchers to find alternative fuel for IC engines. Due to the fossil fuel crisis, the development of alternative fuel technologies has drawn more attraction to deliver the replacement of fossil fuel. Many alternative fuels have been developed and commercialized like alcohols, biodiesel, LPG, CNG etc. pyrolysis is one of the alternative fuel technologies which can produce oil, gas and char from wastes. In this context, the pyrolysis oil obtained from the waste vehicle tyres is receiving renewed interest. Properties of waste tyre oil is compared with the diesel fuel and observed that the properties are quite similar to diesel fuel, so waste tyre oil can be used as alternative fuel in diesel engine. In this paper the study is focused on performance and emission characteristics of waste tyre oil and compares them with diesel fuel.

Keywords: WTO, TPO, Diesel fuel, CI, Alternate fuel

1. INTRODUCTION

In all around the world every year approx one billion tyres are manufacture for off-road vehicles. Almost same number of tyres every year permanently removed from vehicles [1]. Disposal of tyres is a big problem because of the risks posed by tire fires, and because tire piles can provide habitats for diseases vectors, such as mosquitoes. Today there are many methods to manage waste tyres. For instance, The United States Environmental Protection Agency (EPA) suggests, in order of preference, the following: reduce, reuse, recycle, Waste-to-energy, disposal in an appropriate facility. Old tyres recycling can be intended for a wide range of purposes. Among them the most important are [2]: construction bales, carbon products, landfill engineering, expansion joints, stabilisation, sound barriers, retreading, sports/play surfaces, Tyre Derived Fuel (TDF). This last method, i.e. the chances to obtain fuels from waste tyres, is becoming more and more attractive now-a-days, especially in combination with a pyrolysis process (direct combustion can be employed as well), since it shows an environmentally friendly and efficient way to take advantage of waste tyres [3–8].

Though many disposal techniques are present to dispose of the waste tyres, still the problem exists. Pyrolysis of a substance produce value added products such as pyrolysis oil, pyrolysis gas, and char. The pyrolysis of waste tyres, which is a thermal degradation of waste tyres in absence of oxygen, produces fuel gas, liquid oils and a solid residue (char). The pyrolysis gas can be used as fuel for heat generation and the liquid oil can be used as fuel or added to petroleum refinery feed stock. The solid residue from waste tyres contain mainly low grade carbon black and mineral matter that can be reused in tyre production or converted into active carbons. Tyre pyrolysis oil (TPO) is mainly constituted by aromatics and aliphatic hydrocarbons, with some properties, such as calorific value and density, similar to those of Diesel fuel (DF) [9, 10]. While the other properties like viscosity can vary according to the pyrolysis process adopt.

However, its utilization in energy conversion devices, such as internal combustion engines, needs some preventative measures that depend on the specific application. In the case of Diesel engines, TPO, because of its low

cetane number, must be mixed with Diesel fuel or complemented by a cetane improver, for example diethyl ether [11].

Aydin and Ilkiliç [12] carried out a study to optimize the fuel production from waste tyres by pyrolysis and resembling diesel fuel by various desulfurization methods. To minimize high sulfur content in fuel some catalysts were used like CaO, Ca(OH)₂, and NaOH. In addition, effects of variables such as temperature, the catalyst ratio, and the N₂ flow rate on yield were investigated. The sulfur content of the product was observed to be 34.25% lower with the utilization of 5% Ca (OH)₂ in the reaction. In order to make the sulfur content of the product closer diesel fuel, the acetic acid H₂O₂, formic acidH₂ O, and H₂ SO₄ were used in different amounts. The properties of low sulfur tire fuel are very close to diesel fuel but density is slightly higher than diesel.

Al-Lal et al. [13] carried out their research on desulfurization of pyrolysis fuels obtained from waste. In this work, they used two affordable desulfurization techniques without hydrogen to reduce the sulfur content of these three pyrolysis fuels with moderate success that could make them useful as heating fuels. In these methods basically oxidation of sulfur compound occur which present in these fuels with hydrogen peroxide to more polar sulfur compounds like sulfoxides and sulfones that can be later eliminated by methanol extraction or silica gel adsorption. The desulfurization rate was 64%.

In Bangladesh a work on the fuel properties of pyrolysis liquid derived from urban solid wastes was carried out by Conesa et al. [14]. Through the experimental study it is obtained that the optimum reaction condition for waste tyre pyrolysis was at reactor bed temperature of 450°C, for feedstock size of 2-3 cm with a running time of 75 min. At this condition, the liquid yield was 64 wt% of the solid waste tyre feed.

A work on the pyrolysis of sugarcane bagasse for liquid fuel production was carried out by Islam et al. [15]. Through the experiment study it is obtained that at a reactor bed temperature of 450°C for a feed particle size of (300–600) µm and at a gas flow rate of 4 liter/minute, an oil yield of 49 wt% of dry feed was obtained.

De Marco Rodriguez et al. [16] investigates the behavior and chemical analysis of tyre pyrolysis oil. In this study, it is found that tyre oil is a complex mixture of organic compounds of 5–20 carbons with a higher proportion of aromatics. The percentage of aromatics, aliphatic, nitrogenated compounds, and benzothiazole were also determined in the tyre pyrolysis oil at various operating temperatures of the pyrolysis process. Aromatics were found to be about 34.7% to 75.6% when the operating temperature was varied between 300°C and 700°C, while aliphatic were about 19.8% to 59.2%.

2. CONVERSION OF WASTE TYRE INTO OIL

Pyrolysis is one of the technologies which are used to derive alternative fuels, in which organic substances are converted into useful energy. It is a thermo chemical conversion process in which an irreversible chemical change is caused by the action of heat in absence of oxygen. This process yields value added products such as fuels or chemicals in the form of solid, liquid or gas. Without oxygen, the process splits the chemical bonds and leaves the energy stored in the organic substance. The main advantages of pyrolysis include compactness, simple equipment, low pressure operation, negligible waste product and high energy conversion efficiency of the order of 83%.

The oil obtained after pyrolysis is termed as Tyre Pyrolysis Oil (TPO). Pyrolysis of tyres yields liquid fuel, gases, carbon black and steel wires. Tyre Pyrolysis Oil can be directly used as fuel in Combustors and IC engines. Although using in such systems is effective, the complex composition poses huge challenges for use of TPO as a combustion fuel. Presence of Phenolic, Quinoline and PAH compounds leads to high emissions and high maintenance cost.

2.1 Types of Pyrolysis

The main criterion to classify the pyrolysis process is different operating conditions. They are differentiated by residence time of the pyrolysed material in the reactor, process temperature, feed particle size, heating rate etc. These include the following

2.1.1 Slow Pyrolysis

The solid residence time(s) in the reactor is 450–550s, heating rate is 0.1–1, and feed particle size (mm) is 5–50 with temperature (oC) of 550–950. This process enhances char production and is unlikely to be unfavorable for high quality bio-oil production. Also, due to high residence time secondary reaction is favorable as cracking of primary product occurs which could adversely affect bio-oil yield and quality.

2.1.2 Fast Pyrolysis

Fast pyrolysis involves the fast heating of the feed material to a high temperature in the absence of oxygen with a less residence time of the condensable vapor in the reactor. Its operating parameters are solid residence time between 0.5 and 10s, heating rate of 10–200 oC, feed particle size less than 5 mm, and reaction temperature of 550–1200 oC. The technology has received much popularity in producing liquid fuels and a range of specialty and commodity chemicals. Typically on weight basis, fast pyrolysis yields 60%–75% pyrolysis oil with 15%–25% compared to other processes; it has reasonably low investment costs and high energy efficiencies particularly on a small scale.

2.1.3 Flash Pyrolysis

This process is characterized by residence time of less than 0.5 s, high heating rate of more than 200 oC, particle size of less than 0.2 mm, and high reaction temperature of more than 1000 oC. However, the major technological challenge of the process is poor thermal stability, solids in the oil, and production of pyrolytic water.

2.1.4 Catalytic Pyrolysis

Catalytic pyrolysis is a pyrolysis process that includes the use of a catalyst. The catalyst helps to increase the pyrolysis reaction kinetics by cracking down higher molecular weight hydrocarbon compounds to lighter hydrocarbon products. It has been found that the use of catalyst in tyre pyrolysis systems can greatly affects the composition, quality, and yield of products. Examples of catalysts used in tyre pyrolysis include Na₂CO₃, NaOH, MgO, CaCO₃, aluminium-based catalyst, perlite, CaC₂, Cu(NO₃)₂, etc. Operating conditions can determine different product distribution for different catalysts. Pyrolysis catalyst can be grouped based on their method of application. The first group is when the catalyst is added to the feedstock before being fed into the reactor. The second group is when catalyst is added after the feed is already heated up in the reactor allowing it to have immediate contact with vapors, solid, and char. The third group is when the catalyst is placed in another reactor located downstream from the pyrolysis reactor.

The following table indicates the Diesel and Tyre Pyrolysis oil Properties Comparison:

Table.1. Diesel and Tyre Pyrolysis oil Properties Comparison [21]

Sr. No.	Properties	Diesel	Tyre Pyrolysis oil
1.	Density @ 15 °C, kg/m ³	0.830	0.9239
2.	Kinematics Viscosity, cst@40°C	2.58	3.77
3.	Net Calorific Value , MJ/kg	43.8	38
4.	Flash Point, °C	50	43
5.	Fire Point, °C	56	50
6.	Sulfur Content, %	0.29	0.72
7.	Ash Content, %	0.01	0.31
8.	Boiling Point, °C	198.5	70

3. PERFORMANCE ANALYSIS

Cumali İlkılıç and Hüseyin Aydın [24] used alternative fuel production was performed by pyrolysis of waste tyres under nitrogen (N₂) environment and with calcium hydroxide (Ca(OH)₂) as catalyst. The sulfur content of liquids obtained were reduced by using Ca(OH)₂. The liquid fuel of waste tyres (TF) was then used in a diesel engine to blend with petroleum diesel fuel by 5% (TF5), 10% (TF10), 15% (TF15), 25% (TF25), 35% (TF35), 50% (TF50), and 75% (TF75) wt. and pure (TF100).

3.1 Brake thermal efficiency

S muraon [21] the brake thermal efficiency with brake power for TPO-DF blends is compared with the DF and shown in Figure. The brake thermal efficiency for blend is slightly lesser than diesel fuel. The brake thermal efficiency for DF at full load is 29.46 % while with TPO 10 and TPO 30 it is 28.68 % and 28.93 % respectively. The brake thermal efficiency for TPO 50 is 28.39 %. TPO 30 shows higher efficiency at all loads compared to TPO 10 and TPO 50. The reason may be additional lubricity. In general, the engine operated with TPO-DF blends give brake thermal efficiencies marginally higher than diesel fuel.

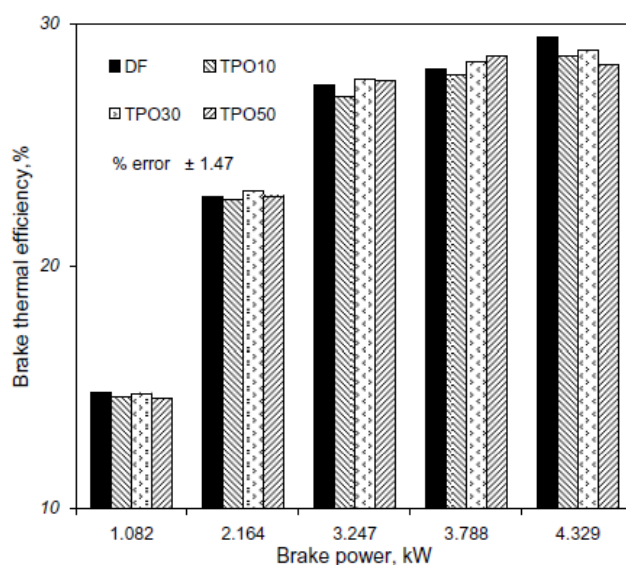


Fig.1 Variation of brake thermal efficiency with brake power [21]

3.2 Brake specific fuel consumption

The TPO-DF blends show higher BSFC value than diesel fuel due to the lower calorific value of TPO-DF blends. The amount of fuel necessary to deliver the same power output with TPO-DF blends is higher with increasing the percentage of TPO. Brake specific fuel consumption (BSFC) vs. engine speed at maximum load is shown in Figure. As a whole, plain DF gives the best results and the worst ones are relative to TPO40, however the differences are significant only at 2500 rpm [22].

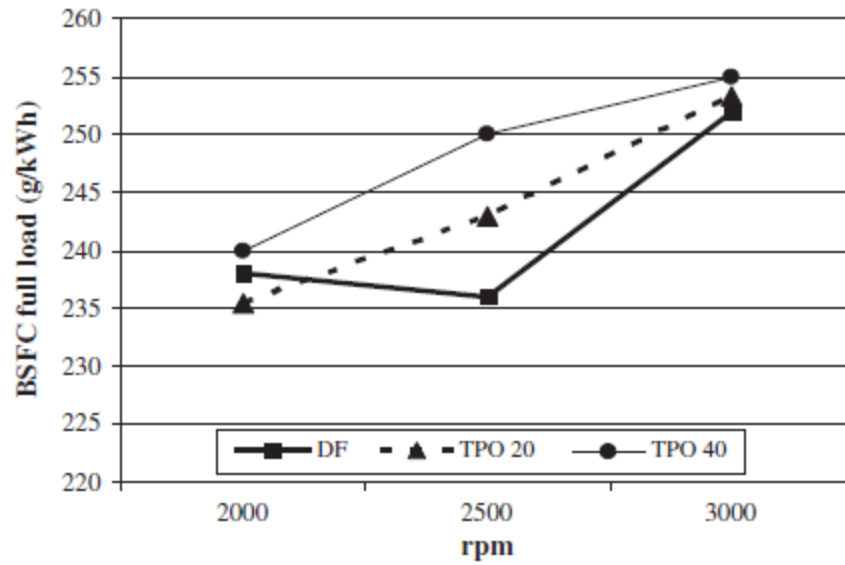


Fig. 2 BSFC vs. engine speed at maximum load.

3.3 Exhaust gas temperature

It may be seen that the exhaust gas temperature increases with increasing load and TPO-DF blends. Poor volatility and high viscosity are the reasons for the higher exhaust gas temperatures for TPO-DF blends. The increase may also probably due to higher heat release rates of TPO-DF blends developed in the premixed combustion [23].

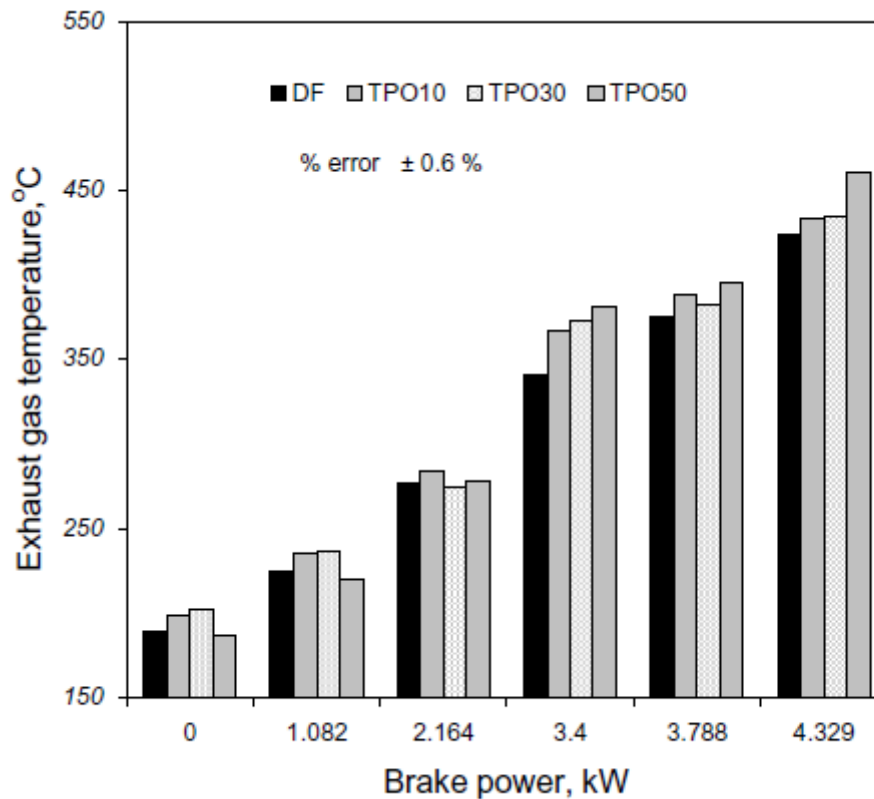


Fig. 3 Variation of exhaust gas temperature with brake power [23]

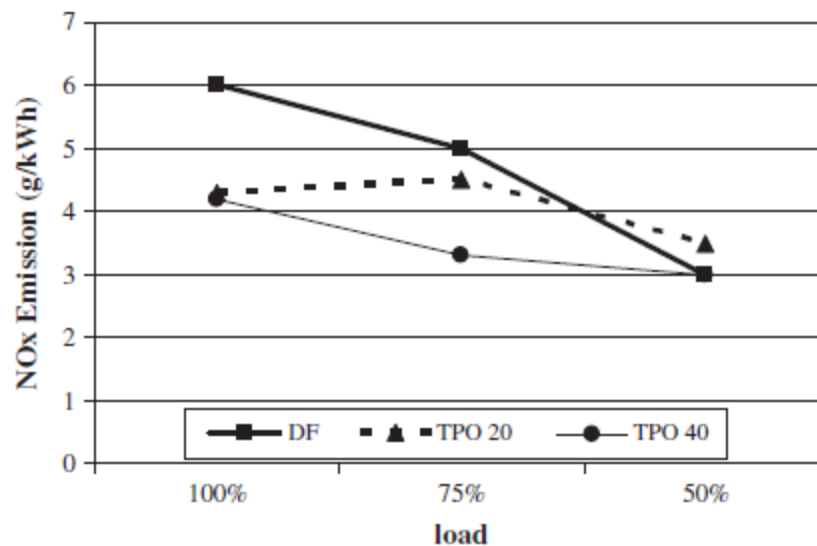
4. EMISSION STUDY

Emission analysis of waste tyre oil content following emissions:

4.1 NO_x Emissions

The NO_x emissions are higher for TPO-DF blends than DF. The NO_x emissions are significantly influenced by two parameters, one is in cylinder gas temperature and the other is residence time. because of the corresponding smaller cylinder volume, during the premixed combustion phase the peak pressure for TPO-DF blends were higher than DF, which is due to higher combustion temperature [25, 26]. This is evident from the higher exhaust gas temperatures from the TPO-DF fuelled engine.

Figure shows NO_x emissions, which are not negligible in Diesel engines. On the whole, they decrease as the TPO fraction in the mixture raises. Due to the decrease of mixture CN, the ignition delay increases, as aforesaid. Therefore the combustion concludes in a larger volume with lower pressure and temperature, which lead to lower NO_x production.

Fig. 4 NO_x emissions vs. engine load [6]

4.2 HC emissions

HC emissions with plain DF and with the two mixtures are similar, however unexpected reductions occur the more, the larger the TPO fraction. This behavior, as observed by other author [27], may be the consequence of the particular TPO physical-chemical characteristics: on one side the low viscosity of TPO (2.9 cSt in respect of 3.5 cSt, on the average, of DF) improves spray atomization; on the other side the large fraction of aromatic and aliphatic hydrocarbons promotes TPO vaporization and, accordingly, combustion velocity (the average boiling point of aromatic and aliphatic hydrocarbons is about 100 C, while a DF contains hydrocarbons having boiling points in the range of 180–360 C [28]). As a matter of fact, these characteristics of TPO contrast with its low CI, which, as aforementioned, leads to a long ignition delay.

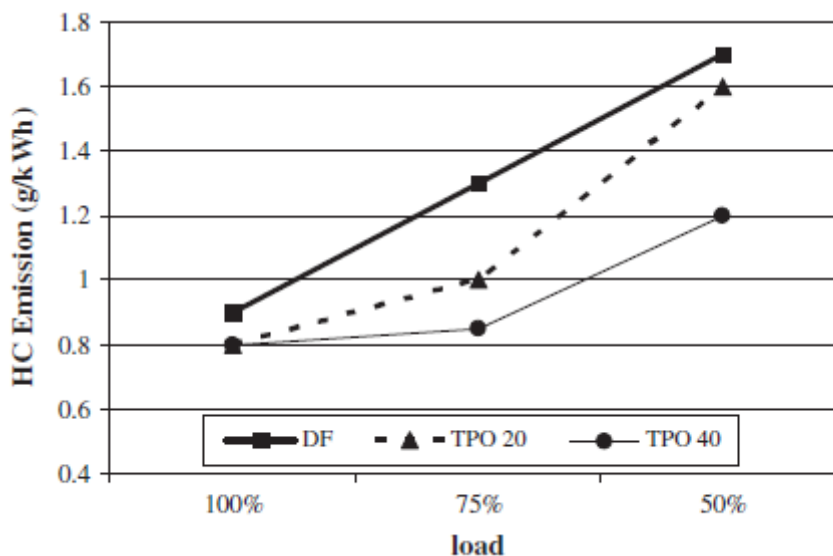


Fig. 5 HC emissions vs. engine load [6]

4.3 Carbon monoxide (CO) Emission

CO for TPO-DF blends increases in concentration on an average of 12 % percent than DF. Diesel engines generally produce lower emissions of CO as they always run on lean mixture compared with gasoline engines, which operates nearer to stoichiometric mixtures [29]. Probably, during the combustion process, the presence of low molecular weight compounds which affect the atomization process, resulting in local rich mixtures produce higher CO emission. At higher temperatures, radicals generated by the decomposition of high molecular weight compounds contained in oil react between themselves and form polymers by condensation. These polymers which exhibit coke-like structure, deposit into the combustion system of the engine [30,31].

As regards CO emissions, they are of the same order at full load while at light loads the best results are obtained with plain DF. The increased CO emission of TPO20 and TPO40 at light loads can be originated, as evidenced by other author [6], by the incomplete combustion of TPO mixtures, which is the result of reduced final combustion temperatures. This is due to the delayed start of ignition with TPO mixture (low CI) and to its high volatility (lower flash point) that generates a cooling effect.

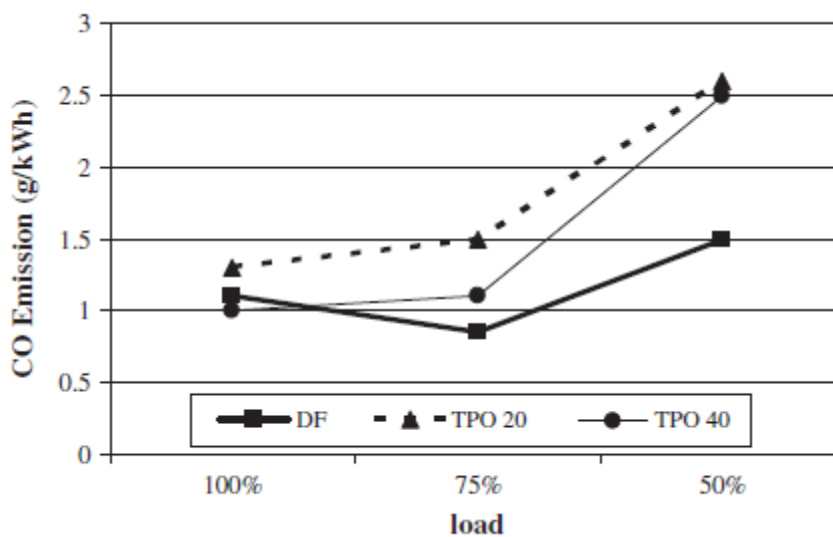


Fig. 6 CO emissions vs. engine load [6]

5. CONCLUSION

Pyrolysis of scrap tyre has done at moderate temperatures in an innovative pilot scale pyrolyser consisting of a thermo-mechanic cracking reactor. The solid fraction could be used as solid combustible in co-combustion with coal or as precursor of activated carbons by physical/ chemical activation. The TPO showed properties such as density, viscosity, calorific value and flash point comparable to those of the commercial automotive Diesel fuels but the content of sulphur is significantly higher and the CI lower than that of DF. The high sulfur content precludes TPO use in road vehicles. However TPO could be used in stationary and marine Diesel engines. Similar cytotoxic potency and no geotaxis effect for TPO/DF blend and DF particulate emissions. Lubricant oil analysis proves a certain level of lube oil contamination due to fuel leaking into the oil sump. As increase in supercharging pressure, the performance is gradually improves. There is a reduction in BSFC at full load with a supercharging pressure. Moreover there is reduction in smoke density due to supercharging pressure. Mixture formation of the fuel and air was improved when the combustion duration became shorter as the injection pressure became higher. When fuel injection pressure is low, fuel particle diameters will enlarge and ignition delay period during the combustion will increase. This situation leads to inefficient combustion in the engine and causes the increase in NO_x, CO emissions. When the injection pressure is increased fuel particle diameters will become small. The mixing of fuel and air becomes better during ignition delay period which causes low smoke level and CO emission. But, if the injection pressure is too high ignition delay become shorter. So, possibilities of homogeneous mixing decrease and combustion efficiency falls down. Therefore, smoke is formed at exhaust of engine.

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