Investigation of Diesel and Biodiesel Soot Oxidation inside a Sample of Conventional DPF

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Abstract

Higher demands of fossil fuels and increase of air pollution due to widely usage of diesel engines has made countries to enhance the after treatment systems. At this study, the soot oxidation of Diesel and Biodiesel is studied with isothermal Thermo gravimetric analyze (TGA) and Mass conversion, apparent activation energy of all samples were analyzed at different temperatures of conversion for each sample. Carbon black N330 was used as a reference material of oxidation. Then a sample of Diesel Particulate Filter (DPF) was used to trap Particle Matter (PM) from engine exhaust from diesel and bio diesel combustion. After trapping the DPF was regenerated by heating up the filter with tube furnace .The results of the tests show significant impact of the fuel properties on soot oxidation. Soot from Biodiesel shows better oxidation behavior and faster regeneration.

Keywords: Soot oxidation, Diesel & Biodiesel soot, DPF regeneration, TGA.

1. Introduction

Diesel engines are widely in use in all over the world due to their higher efficiency in different fields of transport and industry. However the increase in fossil fuel demands and new emission regulations has obliged the countries to legislate new policies and restriction to cope with these two main disadvantages of diesel engines. Increase of fossil fuels price and air pollution has made companies and scientists to look for alternative fuels to compensate the energy demands and emission regulations and meet the new global standards. To do so a dual policy is required to reduce the dependency to fossil fuels and air pollution at a relatively parallel action. For fuel improvement, application of biodiesels is one of the prevalent remedies for this problem among many countries. The biodiesels are more environmental friendly due to cleaner combustion, biodegradability, being non-toxic and lower emission profile as compared to petroleum based diesels [1]. Diesel particulate matter is part of a complex mixture of combustion of diesel engines product which is consists of carbonaceous, unburnt Hydrocarbons and other impurities. The composition of PMs from a diesel engine may vary widely depending on the operating conditions and fuel composition. PM is traditionally divided into three main fractions: solid fraction (SOL), soluble organic fraction (SOF), and sulfate particulates (SO4) that consist of sulfuric acid and water. The SOL of diesel PMs is composed primarily of elemental carbon, sometimes referred to as inorganic carbon. This carbon, which does not chemically bound with other elements, is the finely dispersed carbon black or soot substance responsible for black smoke emission. Hydrocarbons (HCs) adsorbed on the surface of the carbon particles are present in the form of fine droplets from the SOF of diesel particulates. In some researches, this fraction is also referred to as the volatile organic fraction (VOF) [2-7]. Diesel particulate filter (DPF) is a prevalent device for filtration of diesel exhaust PM. The mechanism of DPF is based on entrapment of exhaust PM by the porous material of DPF. After compiling the PM inside DPF, the filter will be regenerated in two main method, active and passive method. In active method, the heat of engine exhaust is responsible for DPF regeneration and the trapped PM will be oxidized by engine exhaust while in passive form, the DPF will be regenerated by the heating up the DPF with a high temperature system separately after removal from the vehicle. At this study, at first step the PM samples were collected from single cylinder engine by application of diesel and biodiesel and TGA and CHN test were done on them. Then a round sample of conventional DPF was used to investigate the trapping behavior of DPF and pressure drop of soot trapping, which is described in methodology section. Finally the DPF was regenerated by high temperature furnace and the results were collected and compared in order to study the affecting elements of DPF soot filtration and regeneration.

2. Preparation

2.1. Fuels

The main characteristics of applied fuels is shown in table 1. More technical data of fuels which were used at this study is shown at earlier technical paper [1].

Table.1 fuel properties.

Fuel properties	Diesel	Biodiesel
Viscosity(mm2/s)	3.205	4.452
Density(g/cm3)	0.82649	0.87482
Calorific value(MJ/kg)	45.8	39.9
Oxidation stability (hr)	158.21	22.86
Flash point (^{o}C)	65.5	198

2.2. The engine, TGA and CHN

The small single cylinder diesel engine, Yanmar, is used for soot generation with PB100 and diesel. The engine was set at 80 % load with 2400 rpm on the Eddy current engine dynamometer (Tokyo plant ED-60kw-LC at KMITL). Metallic filter were used to collect PM and for each fuel new filter were used for collection. Then samples were collected and kept at sealed containers and sent for TGA. CHN test and Isothermal TGA test was done for all PM samples. Each sample was tested at four different temperature including 500, 550 and 600 ^{o}(C). For non-isothermal part nitrogen was used to heat up the sample to desired temperature then air was introduced for soot oxidation for one hour. In order to have a good reference, carbon black N330 is used for TGA test at 600 °(C). The more detailed discussion about TGA test is presented at [4].

2.3 The DPF sample and apparatus

The DPF apparatus and system structure schematic is shown in Fig.1.

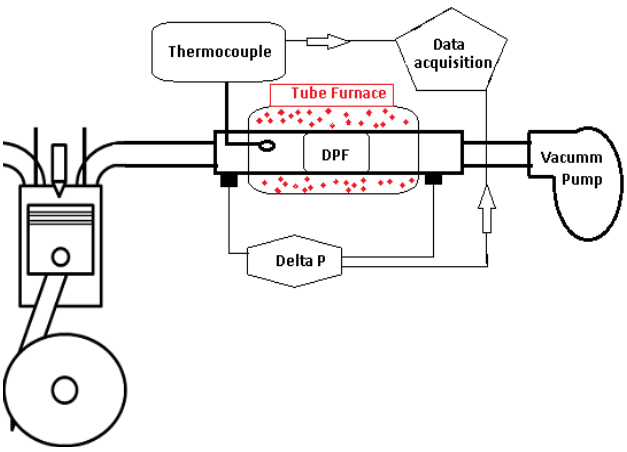
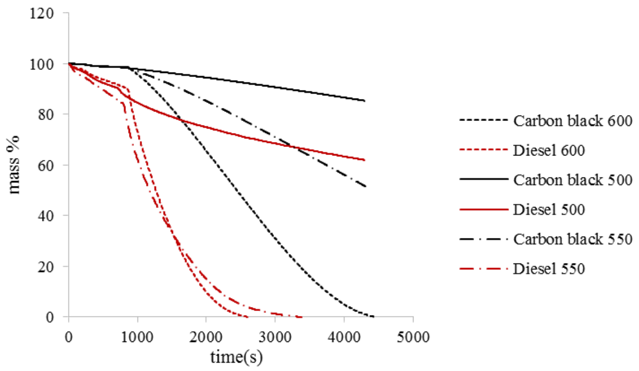


Fig. 1 DPF trapping apparatus and heating system

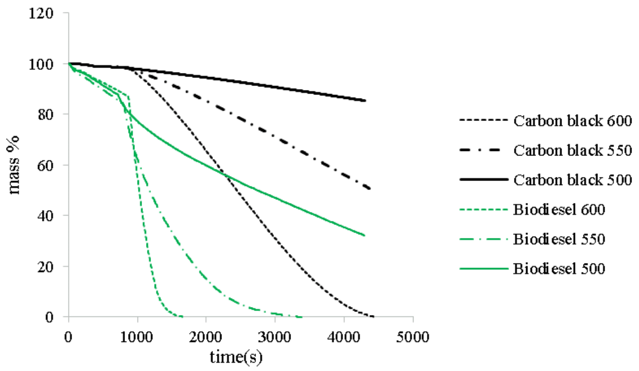
A sample of DPF is held in the middle of a ceramic tube. Two pressure sensors and one thermocouple are connected to the pipe and to a data acquisition card. The inlet is connected to the engine exhaust and the outlet is connected to the vacuum pump. The pressures sensors will measures the pressure drop of the system after soot trapping and at 200 °(c), which is almost close to the engine exhaust temperature. All the collected data were gathered by Lab View program and plotted in excel. At first step the diesel fuel was used and the soot were trapped and after pressure drop got to a constant condition, the trapping phase was stopped and then the filter was heated up to 600 °(c) to regenerate the filter. The same process is done for biodiesel.

3. Results and discussion

The result of TGA isothermal is shown in Fig.2. “(a)” and “(b)” for diesel and biodiesel and both samples are compared with carbon black N330.



“(a)”



“(b)”

Fig. 2 Soot conversion of “(a)”diesel and “(b)” biodiesel soot in TGA isothermal condition.

As seen in figures, in all temperatures for both samples the biodiesel soot sample shows a faster conversion and oxidation trend in comparison with diesel. This is mainly due to elemental compositions of the soot samples and difference of fuel properties which can alter the soot oxidation kinetics and activation energy of the sot samples. More detailed investigation on the soot oxidation kinetics of these two samples are provided at [6]. This can be clear indication of better oxidation behavior of biodiesel PM in comparison with diesel and also impact of fuel properties on PM composition. The general stages of trapping includes 4 phases. At first stage the DPF is clean and pores are empty and ready to trap the PM. At second stage initial trapping begins and soot deposits fill the pores of DPF wall. From second to third stage, the pressure drop starts to rise and at third stage the trapped soot covers the pores. In the final stage the soot cake layer forms on the surface of the wall and pressure drop shows a constant trend.

contributed to several factors including chemical and physical. Based on previous studies [5, 7] the PM size made by biodiesel combustion is smaller than diesel due to different chemical composition of biodiesel and presence of more oxygen in biodiesel fuel results in more complete combustion and provides higher chance for carbon molecules to be oxidized. The density and viscosity of biodiesel is higher than diesel and this will cause advance in injection and also ignition delay so more fuel will be consumed. Besides, Biodiesel has lower calorific value in comparison with diesel and thus more amount of fuel is

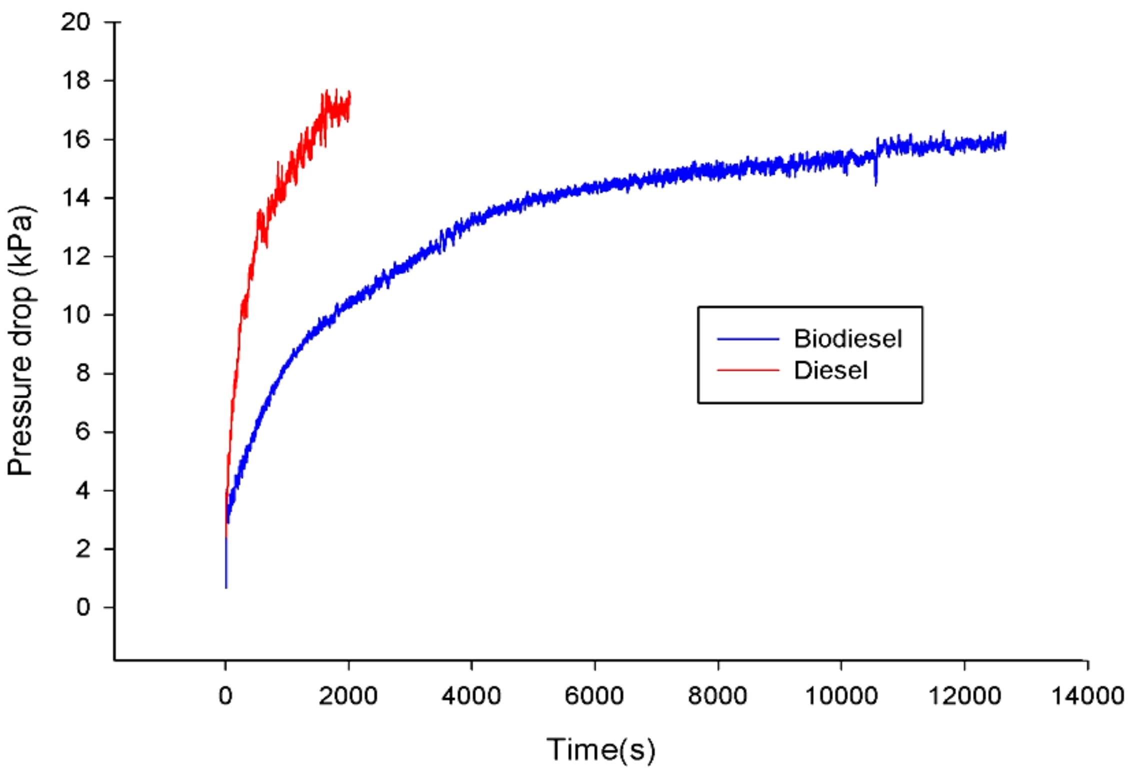


Fig. 3 trapping trend of both fuels samples.

As seen in Fig.3 the trapping time for diesel is much faster than biodiesel and it takes longer time for biodiesel soot to rise the pressure drop to a level which is equal to diesel pressure drop (more than 6 times longer). This can be required. This will lead to longer trapping time in Comparison with diesel and hence the trapping Trend is slower the graph of biodiesel is lesser fluctuated and smoother in comparison with diesel. Figure 4 shows regeneration behavior of both soot samples. The DPF is heated up to 600^0 (C) and to start regeneration of DPF. Regeneration of biodiesel is faster in comparison with diesel (about one hour). This is can be related to soot oxidation kinetics of biodiesel. The lower

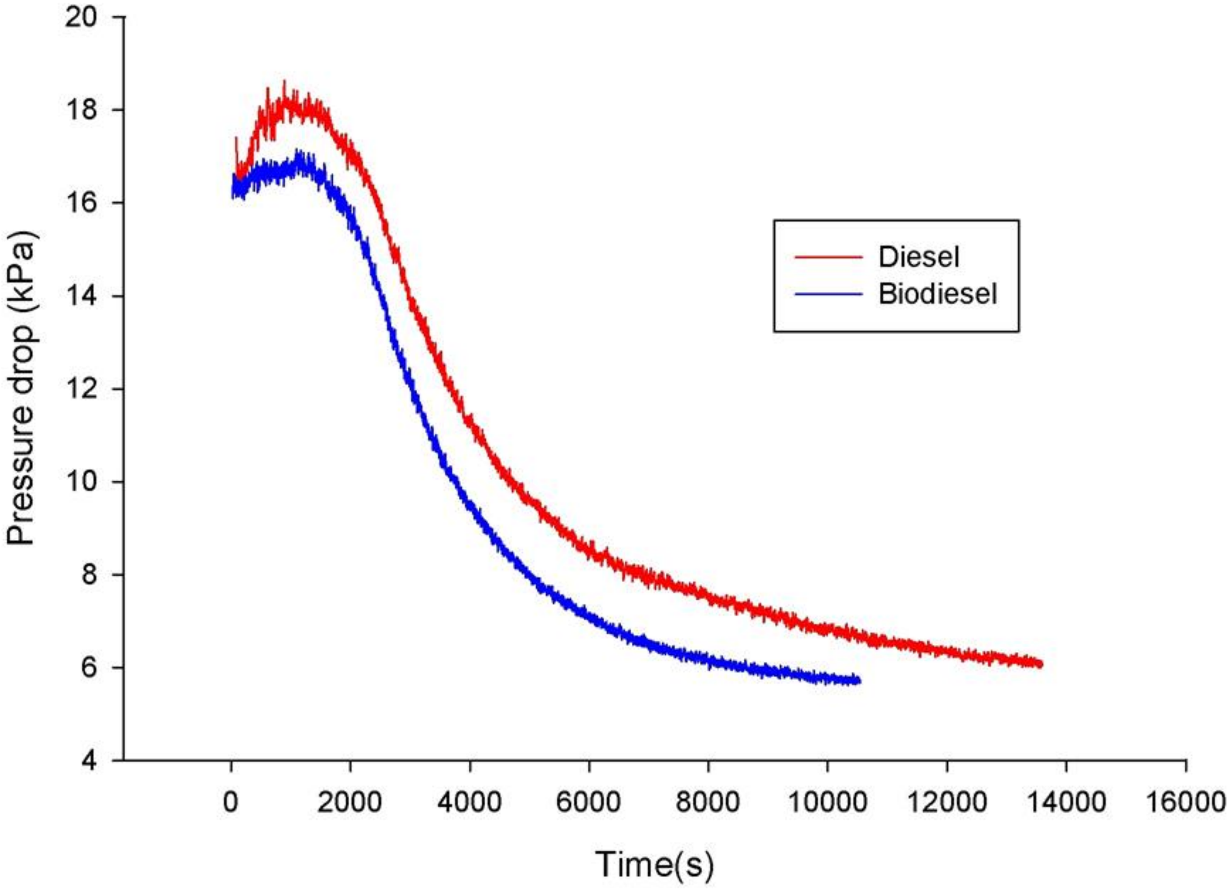


Fig. 4 Regeneration of DPF for both diesel and Biodiesel PM.

Activation energy of biodiesel makes it easier to oxidize and according to previous study at our lab [4, 7] biodiesel PM has much more volatile organic fraction (VOF) and soluble organic fraction (SOF) compositions while for diesel more solid fraction (SOL) and Carbonaceous is seen which makes diesel PM lesser oxidative and the activation energy. In the Same study the PM TGA conversion from both fraction including 80-60 % 60-40% and 40-20% of diesel and biodiesel were divided to three main conversion rate. For initial stage which is mainly VOF and SOF composition the activation energy is 152.91(kJ/mole) and for second and third fraction of conversion is 165.29 (kJ/mole) and for the latest fraction which Usually carbonaceous part is 158.56 (kJ/mole). For biodiesel the activation energy of first fraction Of PM is 146.97 (kJ/mole) and for second and third fraction 156.55 (kJ/mole) and 150.54 (kJ/mole).The Arrhenius plots of the study is Shown in Fig.5 and detailed explanation is discussed in [6]. In the same recent study on soot Oxidation results show the order of reaction for carbon in biodiesel PMs higher than diesel pm and it's 0.74 for biodiesel PM while 0.57 for diesel PM [6]. This indicates that the PM shapes are not completely spherical and doesn't meet shrinking

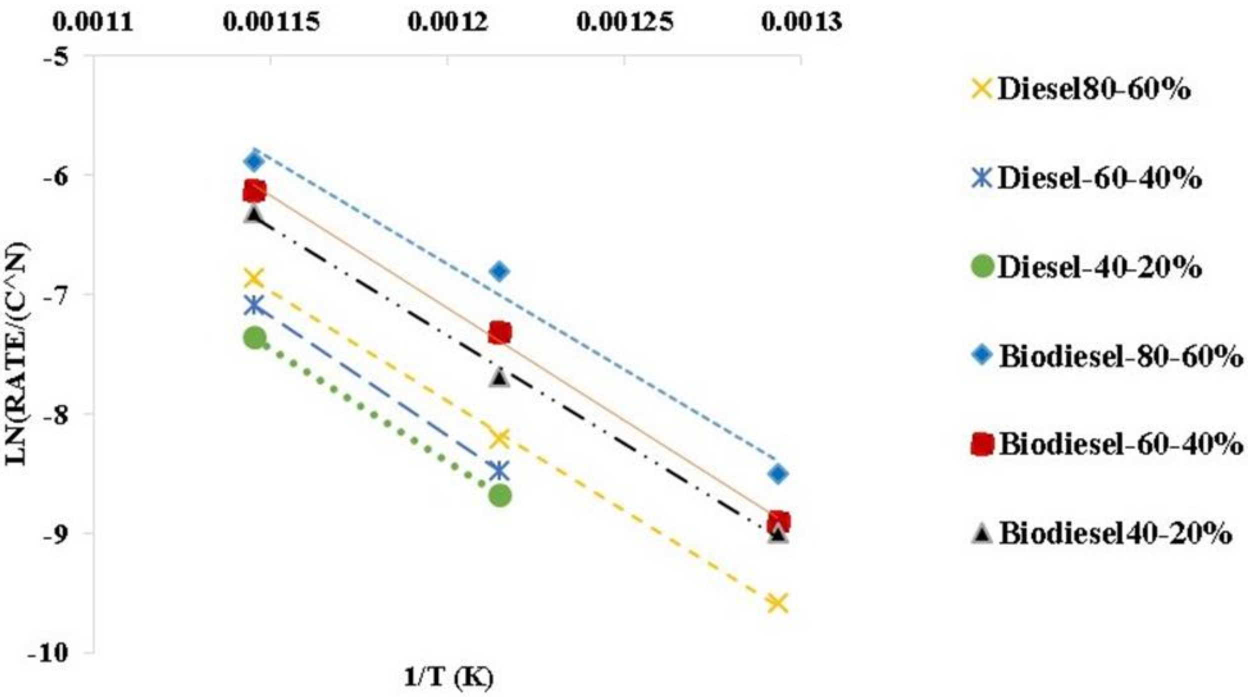


Fig.5 Arrhenius plot of three fractions of PM of Biodiesel and Diesel PM

core model and more active sites for reaction with Oxygen available for biodiesel. The CHN test results shows that diesel PM has higher amount of carbonaceous elements (1.1% H and 81% C) in comparison with biodiesel PM (1.1% H and 74.1% C). This can alter the soot oxidation behavior hence the bonding energy of carbon related molecules are much higher the higher activation energy is required for breaking the old bonds and starting of oxidation. So lower activation energy and lesser carbonaceous components, smaller PM size, higher amount of unburnt hydrocarbon and higher carbon reaction order, *n*, can be the affecting factors which lead to faster regeneration trend. The pump and suction speed and rate might have impact on regeneration but hence the pump for both fuel was same this factor can be omitted. This enables the DPF to work for a longer time when biodiesel is utilized and regeneration.

4. Conclusions

The soot trapping and regeneration behavior of diesel and biodiesel is investigated at this study and results can be summarized as below:

- The trapping time for biodiesel is longer than diesel and this can be related to chemical composition of biodiesel fuel and biodiesel PM and physical characteristics of the biodiesel which can affect engine function.
- The regeneration process for biodiesel PM is faster than diesel due to better oxidative trend of biodiesel PM in comparison with diesel.
- The factors which affect the soot oxidation kinetics such as PM elemental composition, PM size, PM carbonaceous composition and reaction order of carbon can be responsible for different oxidation trend of diesel and biodiesel PM.

- Biodiesel can reduce regeneration time and postpone the trapping duration which makes the DPF working period longer.

Acknowledgement

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7. References

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