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Effects of biodiesel on continuous regeneration DPF characteristics

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Abstract: A critical requirement for the implementation of DPF on a modern engine is the determination of Break-even Temperature (BET) which is defined as the temperature at which particulate deposition on the filter is balanced by particulate oxidation on the filter. In order to study the influence of biodiesel on the Regenerating Characteristics of Continuously Regeneration DPF, Bench test were carried out to investigate the BET of a continuously regeneration DPF assembled with a diesel engine fueled with neat diesel and biodiesel. Test results show that at the same engine operation conditions the fuel consumption is higher for biodiesel case, and also the intake air quantity and boost pressure are lower; the BET for the Diesel fuel is about 310 ℃ while it is about 250 ℃ for the Biodiesel case. When the engine is at the low torque and low exhaust temperature operation condition, CO conversion rate is extremely low, NO_2/NO_X ratio is small; with the increase of torque and exhaust temperature, CO conversion and NO_2/NO_X ratio increased significantly, and the maximum NO_2/NO_X ratio (about 35%) has been measured at 350 ℃. In addition, the DPF has better filtration efficiency for biodiesel PM, and the use of biodiesel to engine assembled with DPF has significant benefits.

1. Introduction

In recent years, with the increasing environmental pollution problems, automobile emissions regulations increasingly stringent. In order to meet the particulate matter(Particulate Matter, PM) emissions requirements in China VI and Euro VI vehicle emission standards, it is needed for vehicle installs a diesel particulate filter in the engine exhaust system(Diesel Particulate Filter，DPF). DPF is currently recognized as the most effective particulate matter (PM) reprocessing purification device[1], which can effectively reduce the engine PM emissions. The attendant problem is that the different pressure across the DPF increases as the PM accumulates in the filter, Therefore, the DPF needs to be regenerated, which reduce the DPF negative impacts on the engine dynamics and economy[2,3].

DPF regeneration requires burning or oxidizing PMs with high carbon content accumulated in the DPF filter[4-6]. It is necessary to increase the carrier temperature to achieve the ignition temperature of PM, or use a catalyst to reduce the PM ignition temperature to the exhaust temperature of the engine. DPF catalytic regeneration is a continuous regeneration method, The promotion of DPF regeneration is carried out by catalytic conversion of NO in the exhaust gas to NO_2, while using the oxidation catalyst to reduce the PM ignition temperature, and finally to achieve complete regeneration of DPF. For continuous regeneration DPF, PM ignition temperature, NO catalytic NO_2 temperature, and DPF PM accumulation and oxidation equilibrium temperature points are three key temperature variables[6]. PM ignition temperature and NO catalytic conversion temperature mainly depends on the catalyst properties, belonging to the universal properties. The equilibrium temperature point for PM accumulation and oxidation is the rate at which the PM accumulation rate in the DPF is equal to the oxidation rate and needs to occur at a sufficiently low temperature to suit the exhaust temperature range in the range of typical diesel vehicle conditions. Which is a particularly important temperature variable that determines whether the DPF is capable of meeting the diesel engine exhaust regulations. Since the equilibrium temperature point depends on the engine emissions and operating conditions parameters, it is not a universal attribute of DPF. There are some studies have shown that DPF equilibrium temperature points are inconsistent in different working conditions, and the reproducibility of the results has been a hotspot for continuous regeneration of DPF[6,7].

Biodiesel is renewable, can reduce greenhouse gas emissions, inhibit the formation of soot, has been used as a substitute for diesel fuel has been widely studied around the world[8-10]. Biodiesel is liquid fuel based on oil crops, waste oil and other raw materials through the transesterification process. It has the advantages of high cetane number, good lubricity and recyclability[11,12], Diesel engines can be used directly with biodiesel fuel[13,14]. A large number of studies show that modern diesel engines using biodiesel as a fuel can directly reduce emissions of pollutants, particularly conducive to reducing PM and CO_2 emissions[5,15,16], In addition, biodiesel can also reduce the combustion temperature of particles in the DPF[17]。

In summary, biodiesel as an alternative fuel can be used directly on the diesel engine, diesel engine fuel properties will affect the changes in diesel engine emissions and conditions, which will change the reprocessing system DPF regeneration equilibrium temperature point. In this paper, petrochemical diesel and biodiesel were used as diesel fuel, and the regenerative equilibrium temperature of continuous regeneration DPF under different working conditions was compared and analyzed by bench test to study the effect of biodiesel on regeneration equilibrium temperature.

2. Test device and method

The engine used for the test was turbocharged common rail diesel engine, the fuel used to meet the national standard of petrochemical diesel and biodiesel. The overall test device is shown in Fig1. The main equipment includes AVL eddy current bench test system, data acquisition system, exhaust analyzer system and generator electronic control unit (ECU), in which AVL eddy current bench test system is used to control engine conditions, fuel flow, Gas and other conditions, the data acquisition system is used to monitor the engine speed and torque, as well as the inlet and exhaust systems, intercoolers, fuel, oil and other temperature and pressure, exhaust analyzer system for the detection of exhaust NO / NO_2 / NO_X, CO, CO_2, O_2 and smoke, etc., ECU can be used to control the engine fuel injection, fuel injection time, EGR rate and other parameters.

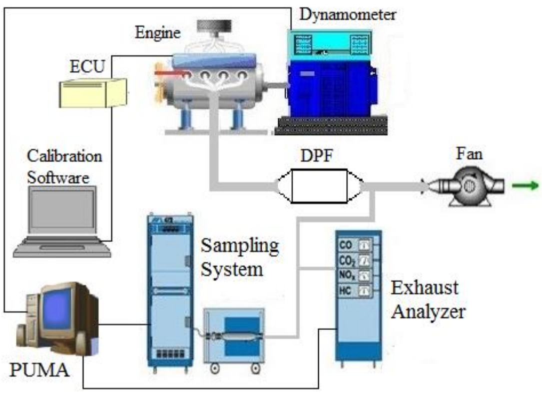


Figure 1. Schematic diagram of bench test

The experiment was carried out by wall - flow continuous catalytic regeneration, DPF installed in the exhaust pipe, oxidation catalytic converter (DOC) installed in the DPF upstream, the layout of the exhaust system is shown in Fig 2. A pressure sensor is provided at the front and rear of the DPF to measure DPF differential pressure. There are three exhaust analyzer sampling points on the Exhaust pipe for emission analysis, The specific location shown in Fig 2. Sampling point 1 (SP1) is located at

IOP Conf. Series: Earth and Environmental Science **69** (2017) 012060 doi:10.1088/1755-1315/69/1/012060

the engine exhaust outlet and upstream of the DOC. Sampling point 2 (SP2) is located downstream of the DOC and upstream of the DPF system. Sampling point 3 (SP3) is located downstream of the DPF.

In order to study the regeneration equilibrium temperature of continuous regeneration DPF, the regeneration equilibrium temperature of DPF was found by performing the test cycle of five steady-state conditions on the test bench. In the test, the engine speed control in the medium speed 2000 rpm, the initial torque of 10 Nm, the engine torque increased by 50 Nm after every 20 minutes, the engine operating conditions shown in Table 1. In the same working condition test, the EGR of the engine was turned off to eliminate the influence of the exhaust gas recirculation on the test conditions. In the same exhaust state test, open the EGR, through the ECU to adjust the engine parameters and EGR rate, to ensure that the two fuel exhaust status consistent.

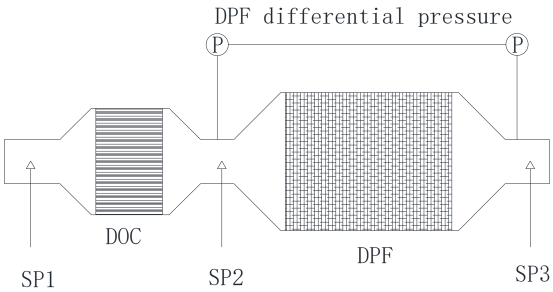


Figure 2. Schematic diagram of aftertreatment equipment

Table 1. Engine test parameters

Mode	Speed/rpm	BMEP/bar	Torque/Nm	EGR/%
Case 1	2000	1	10±2	0
Case 2	2000	4	60±5	0
Case 3	2000	7	110±5	0
Case 4	2000	10	160±5	0
Case 5	2000	14	210±10	0

At the beginning of each cycle test, the PM in the DPF must first be completely cleared, DPF which is used for the test is placed in the oven at 650 ℃ for 20min, so that the residual PM regeneration completely; After the DPF is fully regenerated, the DPF unit is operated on the exhaust pipe. The engine is operated on the gantry for 1.5 h at a speed of 3000 rpm and a BMEP 7 bar. The PM load in the DPF is about 6 g/l, thus ensuring that the initial state of PM loading in the DPF is consistent. After the loading of the PM, the engine carrying the DPF starts at a low speed of 200 rpm at a speed of 2000 rpm, and the tests are repeated between pure petrochemical diesel and biodiesel fuel.

3. Test results and analysis

3.1 The same working conditions test

Diesel engine DPF can effectively reduce PM emissions, the DPF needs to be regenerated using the appropriate strategy after hundreds of kilometers or hours of operation. The time interval between DPF regeneration is entirely dependent on the operating conditions of the engine. In some specific conditions, the engine exhaust temperature is high, DPF regeneration can be done spontaneously.

Diesel engine DPF regeneration temperature (BET) is to achieve DPF continuous regeneration and the key point to measure the DPF pressure drop. By increasing the engine torque, improve the exhaust temperature, analysis of continuous DPF pressure changes, can effectively assess the BET. In the low torque stability conditions, the engine exhaust temperature is very low, generally less than 300 ℃, The exhaust back pressure increases with PM accumulation. When the torque increases, the exhaust temperature increases, DPF filtered PM began to oxidize, when the PM oxidation rate exceeds the accumulation rate, DPF pressure reduction.

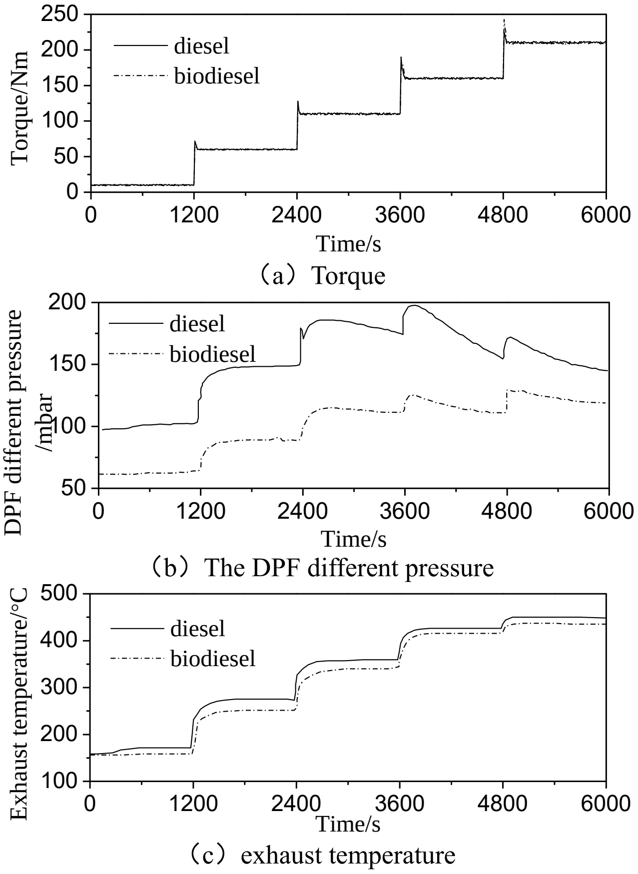


Figure 3. Test results variation at the same working condition

Figure 3 shows the DPF different pressure, exhaust temperature and engine torque variation for diesel and biodiesel fuels in five steady-state cycle tests. As can be seen from Fig. 3b, in case 1, the DPF pressure drop is also low due to the relatively low engine exhaust flow. Figure 3c shown in the two fuel engine operation, the exhaust temperature is lower than 200 °C, Although the increase in DPF pressure drop in case 1 is small, which is also continues to increase, this is mainly due to the fact that the PM in the DPF is almost free from oxidation when the exhaust temperature is low, and PM is always in the cumulative state.

In case 2, as the engine torque increases, the DPF pressure drop increases as the exhaust gas flow increases. At this time, although the exhaust gas temperature is increased, the exhaust temperatures of the two fuels are less than 300 °C as shown in Figure 3c, PM in the DPF gradually accumulating.

As the engine torque increases to 110 Nm in case 3, the exhaust temperature and flow rate increase further, the DPF pressure drop also increases. As shown in Figure 3c, the exhaust temperature of the diesel oil is about 350 °C, the exhaust temperature of the biodiesel exceeds 330 °C. With the increase of the exhaust temperature, the PM oxidation accelerates and the pressure drop curve changes. The drop begins to increase as the torque increases to 110 Nm, then begins to become flat and then begins to decrease.

In case 4, as the torque increases, the exhaust temperature continues to increase, and the DPF enters the full regeneration mode, and the DPF pressure drop rapidly decreases (Figure 3c). This is due to the PM oxidation rate began to rise above the capture rate, DPF PM loading and pressure drop began to decrease.

In case 5, the exhaust temperature and flow rate are further increased and DPF regeneration is continued.

Fig. 3 shows the difference between the two fuel test results. It can be clearly found that the DPF pressure difference of the biodiesel engine is relatively constant in the case 2 (from 1200s to 2400s), while the DPF pressure difference of the diesel engine High, indicating that the oxidation rate of PM in the DPF of the biodiesel engine has begun to equate to the capture rate.

The change in PM oxidation and capture rates can be obtained by calculating the slope of the pressure difference and the temperature. The regeneration equilibrium temperature (BET) can be obtained by analyzing the slope of each step and the slope of the temperature, the slope is positive and the PM trapping rate in DPF is greater than oxidation rate, whereas if the slope is negative, the PM oxidation rate is greater than the capture rate. The slope of the DPF differential pressure gradient and the exhaust gas temperature curve is calculated as shown in Fig. 4, and the curve is defined as the regeneration equilibrium temperature by the corresponding horizontal axis exhaust temperature when the slope of the pressure difference is zero.

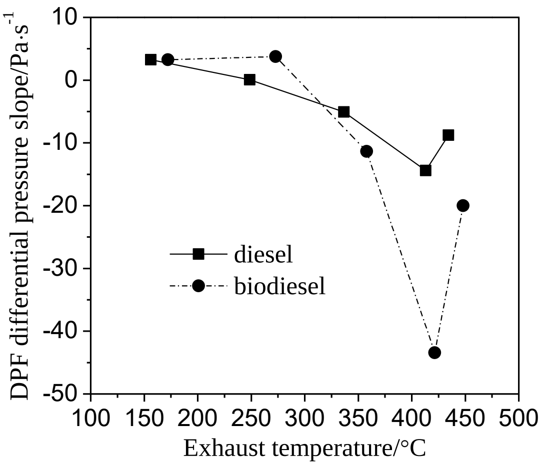
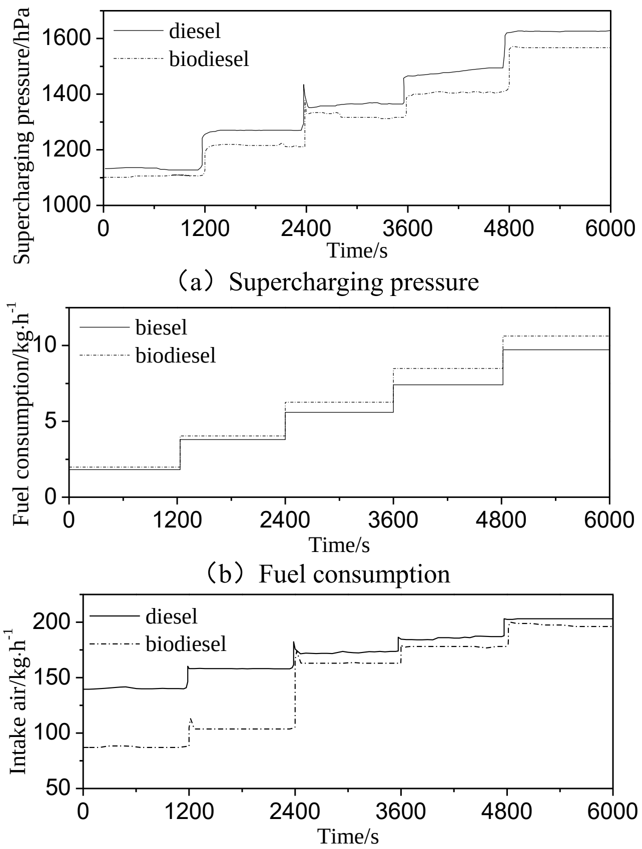


Figure 4. The DPF differential pressure slope

From the variation of the pressure difference between the two types of fuels in Fig. 4, The presence of BET at the DPF of diesel fuel is at about 310 °Coccurs when the BET of biodiesel is present at about 250 °C, BET of biodiesel continuous regeneration DPF is significantly lower than diesel. This is mainly because the emission of NO_X in biodiesel exhaust is higher, which is beneficial to the oxidation of PM [18].

Through the above analysis, it can see that under the same engine conditions, biodiesel can reduce the regenerative equilibrium temperature of continuous regeneration DPF. However, biodiesel has a different chemical and physical properties than fossil diesel, especially for biodiesel, which means that the engine outputs the same power and requires more fuel to be injected. The above analysis of the engine power is the same and without EGR intervention, diesel and biodiesel continuous regeneration DPF regeneration equilibrium temperature of the experimental study process. In order to ensure that the engine burns biodiesel or diesel to achieve the same output power, must be calibrated for different fuels. Therefore, most of the engine parameters (such as intake, boost pressure, fuel injection, etc.) are different from those in the case of diesel fuel when using biodiesel in the test.



(a) Supercharging pressure

(b) Fuel consumption

(c) The intake air

Figure 5. Engine parameters variation at the same working condition

Figure 5 shows the engine without EGR intervention test results for the engine intake, supercharging pressure and fuel consumption of the two fuels under the same engine conditions and . As can be seen from Fig. 5, the difference between the intake air volume, the supercharging pressure and the fuel consumption of the two fuel engines is very significant under the same BET test. Biodiesel fuel consumption is higher, while the intake and pressure is low, this also proves that the same mass of PM mass accumulated in the two fuel tests DPFs is the same, but the DPF pressure measured at the time of engine use of biodiesel is always low throughout the test cycle.

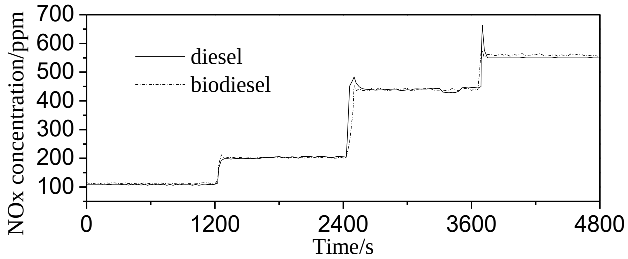
3.2 Equivalent exhaust status test

The above analysis shows that there is a difference in the emission levels of biodiesel and diesel under the same engine conditions when EGR does not intervene. And a large number of studies have shown that NO_X emissions of the engine is very obviously conducive to DPF regeneration, therefore, in order to evaluate the regeneration equilibrium temperature of DPF at the same emission level of the engine, it is necessary to ensure that the discharge temperature and NO_X concentration of the two fuels are consistent.

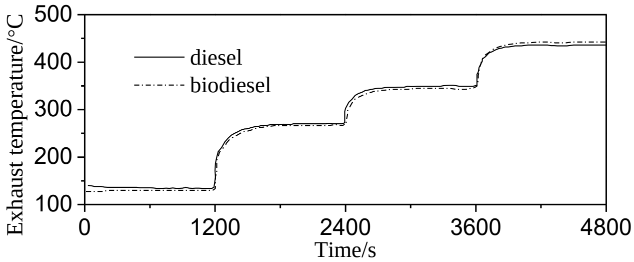
During the experiment, the engine parameters and the EGR rate are adjusted by the ECU to ensure that the output torque, the exhaust temperature and the NO_X concentration of the two fuels are basically the same under the working conditions 1 to 4, as shown in Figure 6. The curve of the test results in Fig. 6 shows that the difference between the emission temperature and the NO_X emission concentration of the two fuels is small by changing the engine parameters and the EGR rate. In the same discharge state, the BET of the biodiesel is about 310 °C, while the diesel fuel BET is about 350 °C. During this test, the BET of biodiesel and fossil diesel were increased, mainly because of the consistency of the two fuel emissions states, the adjustment of the engine parameters and the intervention of the EGR resulted in

IOP Conf. Series: Earth and Environmental Science **69** (2017) 012060 doi:10.1088/1755-1315/69/1/012060

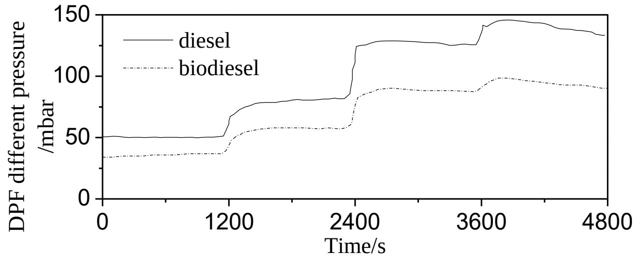
the emissions of both fuels is reduced.



（a） NO_X concentration



（b） Exhaust temperature

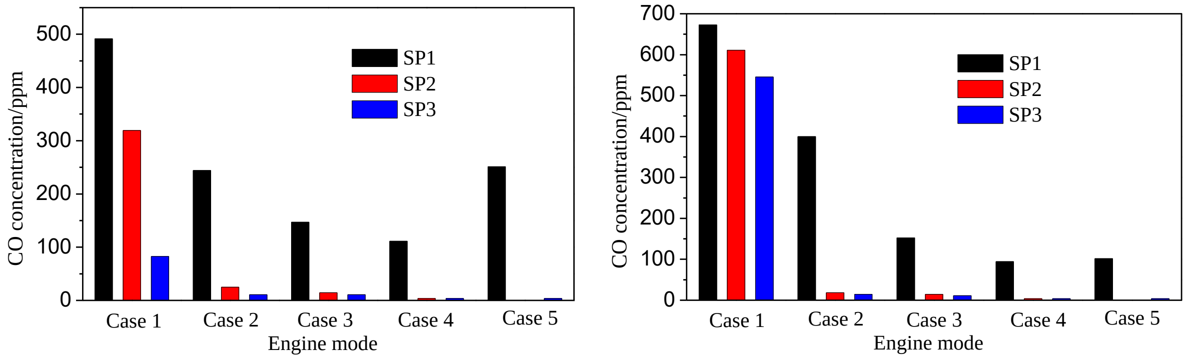


（c） The DPF different pressure

Figure 6. Test results variation at the same emission condition

3.3 Effect of Biodiesel on Emissions

In the same condition test without EGR intervention, the exhaust pollutants CO, NO and NO_2 were carried out at the sampling points SP1, SP2 and SP3 respectively by the exhaust gas analysis system. The smoke level was measured at the sampling point SP3 using an opacity smoke meter. Through the comparative analysis of the results, it is clearly that the two fuels will cause the engine emissions are very different. Figure 7 shows the results of the CO emission from the two fuels. Fig. 7 (a) shows the CO emission results of diesel fuel. Fig. 7 (b) shows the CO emission results of biodiesel. In working conditions 1 and 2, the CO emissions from biodiesel at engine exit SP1 are higher and then the CO emissions are rapidly reduced under other conditions. In addition to Case 1, the DOC in the post-processing system is very effective in oxidizing CO to CO_2 in the exhaust gas, and the efficiency of CO conversion is more than 90% due to the fact that the engine is in low torque conditions when using biodiesel The exhaust gas temperature is very low, about 160 °C, the catalyst in the DOC at this temperature is almost no catalytic oxidation of CO.



(a) diesel (b) biodiesel

Figure 7. CO emission concentration at different sample point

Figure 8 shows the NO_X emission levels for the two fuels. Compared to diesel, the NO_X concentration of biodiesel is about 25% higher in the exhaust. NO_2 is the oxidation catalyst necessary for PM regeneration in DPF. The proportion of NO_2 in NO_X in exhaust gas is very small, which is mainly generated by NO in the exhaust gas. The concentration of NO_2 in exhaust gas have significance impacts on PM regeneration. By comparing the ratio of NO_2 / NO_X in NO_X under different operating conditions, In case 1 and case 2, NO_2 / NO_X ratio is less than 6%, other conditions NO_2/NO_X ratio is more than 20%. The maximum NO_2/NO_X ratio (about 35%) is shown in Case 3, which indicates that the exhaust temperature at 350 °Cis most favorable for NO conversion to NO_2.

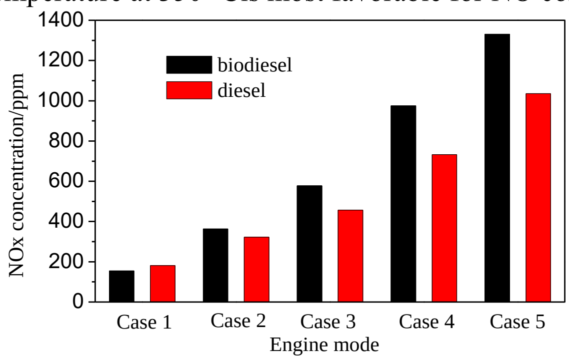


Figure 8. NO_X emission concentration

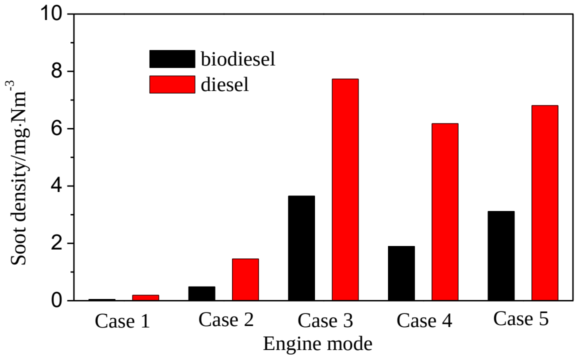


Figure 9. Soot density emission concentration

Figure 9 shows the results of two fuel exhaust opacity measurements based on the end of the exhaust pipe DPF. And then use the Green formula [13] calculated exhaust gas density (mg/Nm^3). It can be seen in Figure 9 that the soot density of diesel fuel emissions is 50% to 70% higher than that of biodiesel under all operating conditions. Indicating that biodiesel can effectively reduce PM emissions by 20% to 50%, which indicates that DPF has better filtration efficiency for biodiesel PM and can more effectively capture PM in biodiesel exhaust.

4. Conclusion

In the same conditions test, compared with the traditional diesel, biodiesel fuel consumption is higher, while the intake and pressure is low. The BET of the DPF of diesel showed at about 310 °C, the BET of biodiesel appeared at about 250 °C, and the BET of regenerated DPF was significantly lower than that of diesel.

Under the same emission state test, the BET of the biodiesel DPF appeared at about 310 °C, the BET of the diesel fuel DPF was about 350 °C. The BET of biodiesel and fossil diesel increased due to the decrease in NO_X emissions

Under low torque conditions, the engine exhaust temperature is low, CO conversion in the exhaust gas is low, as the torque increases, the exhaust temperature increases, the efficiency of CO conversion is significantly improved. At low torque conditions, the NO_2/NO_X ratio in the exhaust is small and the

NO_2/NO_X ratio increases as the torque and exhaust temperature increase, The NO_2/NO_X ratio is the highest when the exhaust temperature reaches 350 °C. DPF has better filtration efficiency for biodiesel PM, and can more effectively capture PM in biodiesel exhaust.

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