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Performance of Commercial Diesel Detergent

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12 types of commercially available diesel detergents are chosen for detergency evaluation by a simulation bench test. Some metal components they contain are analyzed with atomic emission spectrometry. There are also some impacts of these detergents on the power, fuel consumption and soot emissions of diesel engines as investigated profoundly here. Test results show that various types of detergent products in the market take on greatly different performances; the mass of deposits formed on the parts decreases and then increases as more detergent is added; the ash-based detergent can effectively reduce the soot emissions of the engine; the addition of the detergent has no significant impact on the engine power and economy.

1. Introduction

During the operation of the vehicle, as the working time of engine continues to accumulate (Żak et al., 2014), deposits such as soot will generate at the fuel spray nozzles (Sendilvelan and Sundarraj, 2016), inlet valves and combustion chambers due to incomplete combustion and other factors (Vincent, 1994), thus causing engine power loss and severely impacting the performance of the engine. Diesel detergent is a kind of surface active material with polar groups that can be adsorbed on engine deposits (Shahir et al., 2014) and sparsely disperse them into fine particles easily dissolved by the fuel and rinsed out (Gulzar et al., 2017). It can be used as detergent and dispersant for the engine nozzles, etc. to ensure the normal operation of the engine (Marino et al., 2016).

Diesel detergents are classified into ash-based and ashless types according to whether they contain metals (Tian and Xiong, 2010). Ash-based detergents include typical calcium sulfonate and high-basic-value borate sulfonate (Curtis et al., 2003), which can effectively suppress the formation of soot and facilitate full combustion of diesel (Birgel, 2008). According to pertinent literature published in recent years, new quaternary ammonium ashless detergent (Reid and Burgess, 2016) has become the hotspot in academic circles due to its higher cleaning efficiency and better detergency (Bush et al., 2015). This paper makes an evaluation on the detergency property of commercially available diesel detergents and investigates whether they contain some metal components. Engine bench test is also cited here to reveal how well these detergents are on the diesel engines (Beck et al., 2014).

2. Test

2.1 Test devices and fuels

There are Vehicle diesel detergent detector L-3 produced by Lanzhou Victory Petrochemical Instrument Ltd; Inductive coupling plasma emission spectrometer (ICP-AES, GENESIS, SPETRO); engine F6L913 produced by Beinei Diesel Engine Co., Ltd; engine measurement and control device PowerLink FC 2000 produced by XYDC; electric eddy current dynamometer GW250; smart fuel consumption meter FC 2210; opacimeter NHT-6 produced by Nanhua Instrument Co., Ltd. The test uses commercial No.0 vehicle diesel (reported as 0#) with physicochemical indexes in accordance with GB 19147-2016.

2.2 Test program

Detergency evaluation: 12 types of diesel detergents available in domestic and foreign markets are chosen and added to 0# base diesel, reported as 1# ~ 12#, at a ratio of 300μg·g-1. Simulation bench test is conducted

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for the equivalent sample on even ground using the vehicle diesel detergent detector L-3. It can determine the cleanness of additives to the engine by measuring the weight of deposits on the collector plate. Each group of tests are repeated three times to obtain a mean value.

Analysis of metal components: take 0.5g from each of 12 detergents and dilute them into 10g with jet fuel, respectively, and number them as 1.3.1. Inductive coupling plasma emission spectrometer is used to measure the contents of a total 20 elements, i.e. Cu, Ag, Ni, Sn, Pb, Ti, V, Cr, Cd, Fe, Mn, Si, Al, Zn, Na, Mg, B, Ba, Mo in each sample.

Bench test: in accordance with GB/T 18297-2001 Performance Test Code for Road Vehicle Engines, a comparative test is conducted on the external characteristics of the engine with 0# pure diesel and the diesels added with 1# ~12# detergents. The principle of external characteristic test is to set the diesel engine to operate stably under the rated operating conditions so that it may reach the thermal equilibrium (Liu et al., 2016), change the engine speed while maintaining the throttle at the maximum percentage, and take 7 test point at equal interval of 200r·min-1, measure the engine power, fuel consumption, and soot emissions (Iorio et al., 2016). Power is an important index for measuring the engine power performance, fuel consumption is one for engine economy. Carbon emission is used to determine the exhaust index of engine. Under the same working conditions, the mean value of change rates in the measurement indexes at all operating points is regarded as the average change rate. Each operating point is measured 3 times, and the measurements are averaged to reduce errors (Seddak and Liazid, 2016). After the engine replaces the fuel, it should be tested at idle speed for 30 minutes prior to the test in order to avoid the impact of replaced fuel on the test results.

3. Results

3.1 Detergency evaluation

Table 1 gives the results of the detergency evaluation on 0# pure diesel. The mean value of the results from 5 parallel tests are 5.5 mg and the variance is 0.028. The instrument repeatability shows good under the test conditions.

Table 1: Weight of 0# base diesel deposits

No.	1	2	3	4	5	AVG
Weight of diesel deposits, mg	5.7	5.3	5.6	5.7	5.4	5.5

Mass of 0 # pure diesel deposits is recorded as S1=5.5mg, and S2 after the addition of detergent, cleaning efficiency δ of detergent can be calculated as follows:

$$\delta = \frac{S_1 - S_2}{S_1} \times 100\% \quad (1)$$

A detergency evaluation is performed on 12 types of detergents and the results are shown in Table 2 and Figure 1.

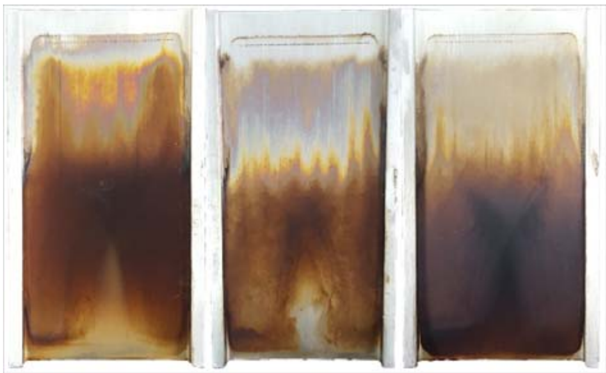

Figure 1: Detergency evaluation results of 0# pure diesel (left), 8# (center), 1# (right) products

Table 2: Detergency evaluation results

No.	1#	2#	3#	4#	5#	6#	7#	8#	9#	10#	11#	12#
Weight of diesel deposits, mg	7.1	5.6	7.3	9.2	11.5	6.0	9.3	4.9	8.2	8.4	5.0	5.1
Cleaning efficiency, %	-	-	-	-	-	-	-	10.9	-	-	9.1	7.3

As shown in Table 2, these detergents have quite different cleaning efficiencies. Among them, there are 3 detergents which have good cleaning effect, 8# product has the best cleaning effect up to 10.9%. As shown in Figure 1, 1# product generates the deposit deeper in color than pure diesel does due to the poor cleaning effect of some detergents available in the market and their self-sediments that leads to increased deposits.

3.2 Analysis of metal components

Analysis results of the metal components contained in the 12 products are shown in Table 3, and the undetected metal elements have been omitted.

Table 3: Analysis of detergent metal components

Metal, $\mu g \cdot g^{-1}$	1#	2#	3#	4#	7#	9#	10#	12#
Mn	-	-	-	84.02	-		-	-
Si	-	-	-	-		58.80	50.84	-
Na	-	-	-	-	-	26.32	-	
Zn	-	-	-	-	-		-	31.14
Mg	-	-	-	-	-	22.88	-	-
B	20.12	41.50	109.28	-	-	33.34	-	-
Ca	-	-	65.18	-	54.26	130.58	-	92.24
Sum, $\mu g \cdot g^{-1}$	20.12	41.50	174.46	84.02	54.26	271.92	50.84	123.38

As shown in Table 3, 5#, 6#, 8#, and 11# are ashless detergents (metal-free does not appear in the table), and the rest are ash-based detergents, among which there are a lot of the detergents containing B and Ca, and detergent 9# contains the highest metals.

3.3 Detergent dosage

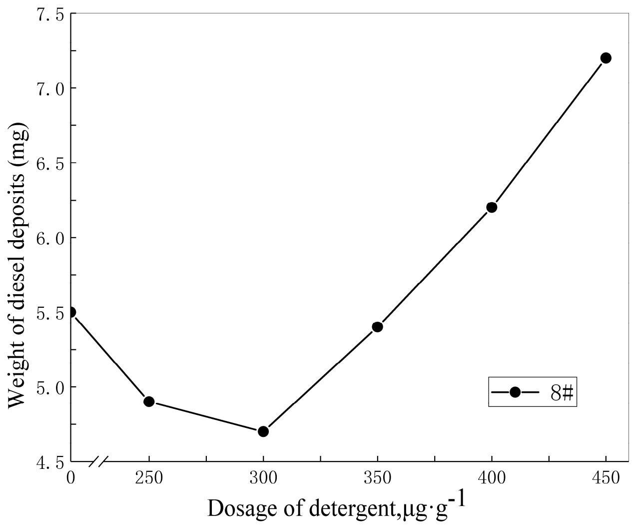

Figure 2: Relationship between the dosage of 8# detergent and weight of deposits

8# detergent has the best cleaning effect and does not contain metal components. Change the dosage of 8# detergent to measure what is the impact it has on the detergency, as shown in Figure 2. It is obvious that the weight of deposits decreases and then increases as the dosage of detergent grows, and is lowest at 300μg·g-1, at this time the best cleaning effect is obtained to be 14.5%. This is because a proper dosage of detergent can play a function to rinse out the deposits as it ncreases. The self-sediment weight of the detergent counteracts the cleaning effect, resulting in an increase in the mass of the deposits. It is necessary that an appropriate dosage of detergent should be added when using detergents.

3.4 Impact of detergents on the engine power performance

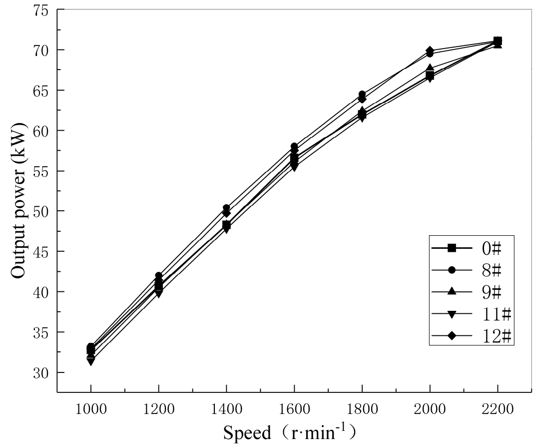

Figure 3: Comparison between engine output powers

The engine output powers when refueling with 0# pure diesel and diesels added with 8#, 11#, 12# detergents and 9# detergent which contains the highest metal component are compared, as shown in Figure 3. Compared with 0# pure diesel, the engine powers with 8# and 12# detergents added increase by an average of 2.39% and 2.08%, respectively, while that with 11# and 9# detergents added decrease by an average of 1.48% and 0.29%, respectively. Detergent can improve engine combustion conditions by cleaning soot deposits away from some parts such as nozzles and inlet valves to recover engine power. The engine under this test works normally without power loss, so that detergent has no significant impact on the engine power performance.

3.5 Impact of detergents on soot emissions from engines

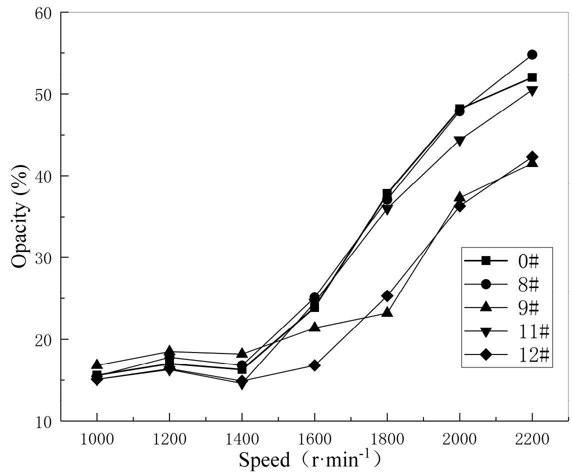

Figure 4: Comparison between soot emissions

The comparison of the soot emissions of engine powered by 0# pure diesel and diesels with 8#, 9#, 11#, and 12# detergents is shown in Figure 4. Diesel soot is a tiny solid particle composed of carbon in a local oxygen-poor and oil-rich area under high temperature and high pressure conditions. In this test, soot emission is measured by an opacimeter. The greater the opacity value, the most the emissions of soot. As shown in Fig. 4, soot emissions increase as the speed escalates within the specified range. Compared with 0# pure diesel, 9# and 12# detergents have the effect of smoke abatement, and their soot emissions are reduced in average by 9.1% and 17.3%, respectively, and the soot emissions is reduced at a high rate with the increase of the speed. The reason of it is that 9# and 12# detergents all contain metal components, from which metal cations produced during the combustion can reduce the activation energy of the fuel molecule C–H bond and accelerate the diffusion and oxidation of fuel molecules, thus suppress the formation of soot. Along with this, the oxygen substitution in the metal oxide produced by combustion can catalyze the chain reaction and improve the combustion further to reduce the emission of soot.

3.6 Impact of detergents on the engine economy

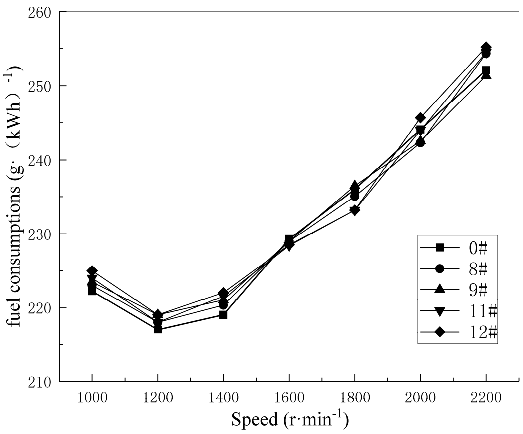

Figure 5: Comparison between fuel consumptions

The fuel consumptions of engine powered by 0# pure diesel fuel and diesels with 8#, 9#, 11#, and 12# detergents are shown in Figure 5. It can be seen that under the full loads, the change rules of curves are consistent, and the fuel consumption drops and then rises with the escalation of the speed, while the addition of the detergent has no significant impact on the fuel consumption of the engine.

4. Conclusions

Diesel detergent is a new type of product that appears on the market. Its specific function is to remove engine fouling, reduce engine power loss, and prolong the service life of the engine. In recent years, there have been many evaluation standards for diesel detergents. The purpose is to screen diesel detergent products. In this paper, common domestic and foreign diesel detergents were selected on the market, and the cleaning efficiency was evaluated by two methods: sedimentation weight gain method and engine bench test. The deposition weight gain method is to make the heated diesel uniform metal plate, accelerate the coking process of diesel, and compare the deposition weight of blank diesel and detergent-added diesel. The engine pedestal test characterizes the role of diesel detergents by detecting changes in fuel consumption, power, and emissions during engine operation, as well as changes in fuel economy, emissions, and power. In general, the diesel detergent products in this article have a limited role in actual use, and the quality and efficacy of diesel detergents on the market are quite different. The cleaning efficiency of individual products is too low or even has no cleaning effect. In view of this situation, it is recommended to strengthen the quality control of diesel detergent products.

The detergency properties of diesel detergents available in the market are quite different. Self-deposition weight of some detergents counteracts its cleaning effect, thus resulting in a poor cleaning efficiency. Excessive dosage of detergents can lead to increased deposits so that an appropriate dosage of detergent should be required for diesel.Addition of ash-based detergent to pure diesel can effectively reduce engine soot emissions.Powers and fuel consumptions of engine powered by pure diesel and diesels with detergents are roughly consistent, which implies that the addition of detergent has no significant impact on the power and economy of the engine.

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