Research on Filtering and Regenerating Trap for Diesel Exhaust Particulate

XIAOLU LI[1], XU WANG[2], LIJUN XU[1], JUAN FENG[1], JUN WANG[1],
HONGYAN CHEN[1], YING LI[1], BAOPING XIAO[1], XUEFEI ZHAO[1]
1. School of Electromechanical Engineering
China Jiliang University
Xueyuan Rd., Higher Education District, Hangzhou, Zhejiang Province
2. School of Humanities
Zhejiang University
Xixi District of Zhejiang University, Hangzhou, Zhejiang Province
PEOPLE REPUBLIC OF CHINA
lxl2006@cjlu.edu.cn

Abstract: A new filtering and regenerating trap for Diesel exhaust particulate is presented, taking the honeycomb ceramics and electric heating elements as filtering components, burning out the smoke by the electrical divided-area heating, and reducing the regenerating time through the promoter. The experimental results indicate that its filtering efficiency is relatively high, up to 70% ~ 90%. All the more, its regenerating time is short.

Key-Words: Filtering; regenerating; Diesel engine; Particle; Promoter; Electrical heating

1 Introduction

Diesel engines have drawn great attention from all over the world, and the usage of diesel vehicles is increasing rapidly because diesel engines have higher efficiency than gasoline engines. In 2000, the automobile output was near 2,070,000 in China, and some 30% of them used diesel as fuel. In the first half year of 2005, the agriculture vehicle production was up to 992, 000. In China, the agriculture vehicles almost fuel with diesel. One of poisonous emissions in Diesel is the smoke, which harmful to human beings and environments. So, many countries are making more and more strict regulations. For example, in Beijing, the vehicle emission standards will be enforced to the level of Euro III from July 1 2007, and Euro IV possibly from 2010, which is beneficial to the 2008 Olympic Games. It is necessary to research and develop the after-treatment technology of particulate matter from diesel vehicle exhaust.

At present, many Diesel-smoke after-treatment technologies are studied and applied. Among these technologies, the Diesel particle filtering and capturing technology is successfully commercial, which mechanical filtering principal is the collision, interception and diffusion in the filter, including the wall-flow honeycomb ceramics, foam ceramics, metal wired screen and fibers [1]. As to the cyclone separating technology, the centrifugal force is manipulated to separate the particulate matter from diesel exhaust before the cyclone separator by adding the flocculants or setting a flocculator to enlarge the particles, since the particulates are too small to separate [2]. The electrostatic agglomeration and collection method is to make use of the added electric field to collect the charged characteristic smoke by the electrostatic adhesion [3]. But its cost is expensive since the difficult insulation design, low capturing efficiency, bulky supplementary device and sophisticated structure. The huge wet purification technology not only could decrease the Diesel emissions sharply, but also reduce the exhaust temperature and lower gas noise. Unfortunately, this Diesel after-treatment technology is only applied at those fixed locations. The aim of catalytic oxidization is to develop a new high-efficient catalyst to remove PM-NOx simultaneously [5]. A study of catalytic PM-NOx removal was carried out by Liu using real diesel particulates by the Temperature Programmed Reaction (TPR) technique, which mixed metal oxide catalysts, $Cu_{0.95}K_{0.05}Fe_2O_4$ and $La_{0.9}K_{0.1}CoO_3$, were loaded on γ-Al_2O_3 spherules and a diesel particulate filter (DPF) by the dipping method [6]. In 2001, Ford Motor Co. reviewed the plasma assisted catalyst technology applied in the particulate matter after-treatment of Diesel engines, and argued that there were a lot of problems to be solved [7].

So, developing an inexpensive high-efficient small Diesel particle filtering and regenerating trap is the necessary requirement of Diesel exhaust control.

2 Filtering and Regenerating Trap

This paper presents a simple high-efficient Diesel filtering and regenerating trap. The filtering components are composed of the honeycomb ceramics and metal fibers, and some of metal fibers are used as the materials of divided-area electrical heating. The high active catalysts are dipped on the filters to increase the temperature of carbon particle oxidation. The honeycomb ceramics are showed as Fig.1, and its specification as Table 1.

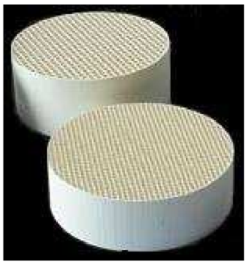

Fig.1 Honeycomb Ceramics

Table 1 Specification of Honeycomb Ceramic

Material	Cordierite
Size mm	Φ200×50
Porosity holes / inch	16
Wall Thickness mm	0.4
Number	2

2.1 Promoter Coated in Honeycomb Ceramic

The traditional regeneration of the divided-area electrical heating spends a lot of time and consumes more electric powers. Therefore, the filter core is usually burned out by the high temperature and temperature gradient or cracked by the heat shock. As the promoter is coated on the filter core, it could increase the temperature of carbon particle regeneration and shorten the regenerating time because of itself radiation thermal to accelerate the particle combustion. The metal oxidation, metal carbonization and metal nitride, which all have the high radiating capacities, are used as the far-infrared radiation coating promoters. The major factors impacting its radiating capacities are the constituents, temperature, wave length, surface state of materials, coating thick and operating time. In order to make the high radiance coating in the wide wavelength extent, many kinds of metal oxidation and metal carbonization are mixed. Although its radiances decrease a little, its thermal conversion rates improve, and its radiation intensity curves change slowly. In this experiment, the promoters are completed through coating the mixtures evenly on the honeycomb ceramics by the dipping method.

2.2 Divided-area Electrical Heating

The divided-area electrical heating element is 0Cr25Al15, and its character parameters are showed as Table 2.

The different diameter wires are wrapped each other forming very compact components. The cross wires are put into the honeycomb ceramics as the electrical elements and filtering components as exhibited in Fig.2. The wire current is 3A as it appears red. The filter has two ceramics, and each of them has 26 heating areas. The resistance is 1.6Ω at each area, and its power 360W. The divided-areas of electrical wires are showed as Fig.3.

Table 2 0Cr25Al15 Character Parameters

Molecular formula	0Cr 25Al15
Max. working temperature °C	1250
Resistivity (20 °C) $\Omega\cdot mm^2\cdot m^{-1}$	1.4~1.45
Temperature coefficient of resistance $\times10^{-5}$ °C	4.3~5.0
Density $\times10^3$ $kg\cdot m^{-3}$	7.1
Melting point °C	1500
Organism	Ferrite
Application	< 1100 °C

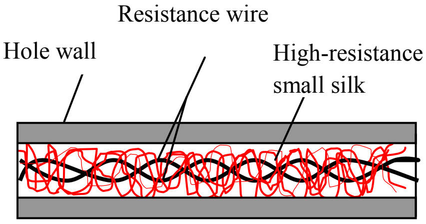

Fig. 2 Filtering Component

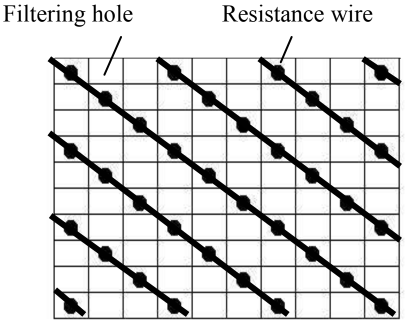

Fig. 3 Divided-Area Electrical Heating

To get the temperature in honeycomb ceramic holes changing with heating time under 24V voltage, the copper-constantan couple is inserted into the honeycomb ceramic. The measurement results are depicted as Fig.4. As can be seen from the diagram, the smoke could be ignited since the heating temperature is up to 600 °C, while the exhaust temperature is usually 200~500 °C.

2.3 Design Requirements of Filtering and Regenerating Trap

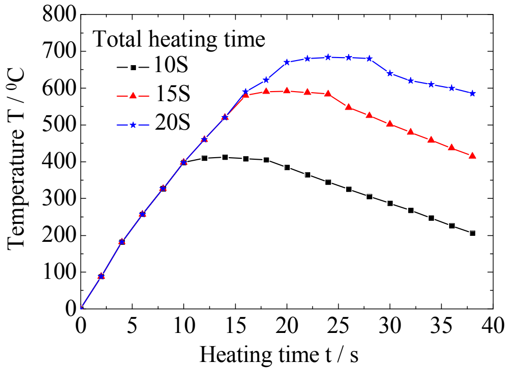

Fig. 4 Temperature in Honeycomb Ceramic Changing with Time

The filtering and regenerating trap should have high filtering efficiency, appropriate size and low flow resistance. If the flow resistance is high, the exhaust back pressure rises, and this will result in consuming more effective power, more specific fuel consumption and growing up emissions. As the size of filter is appropriate, its universal property is popular. Moreover, the filter design should provide reliable leakage, rational heating wire layout and excellent reliability.

3 Experimental apparatus

The experimental apparatus is demonstrated in Fig.5, and the specification of experimental engine and physical and chemistry characteristics of diesel fuel are exhibited in Table 3, 4 respectively.

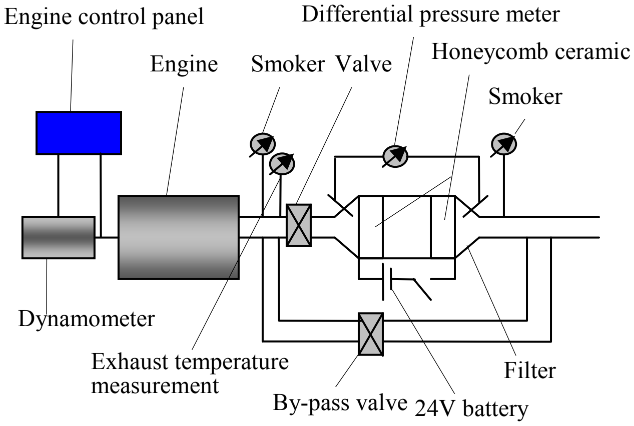

Fig. 5 Experimental apparatus

An eddy current dynamometer and 0301-type engine control panel (including an automatic oil consumption meter) are used, which made in Hangzhou Yike Mechanical-electrical Institute. The smoke is metered by a FQD-102A digital BOSCH smoker, which accuracy is 0.1BSU. The differential pressure of the filter is gauged by a U-type mercury tube, while the speed of Diesel engine is recorded by a magneto-electricity rotary transducer.

Table 3 Experimental Engine Specification

Engine model	6110B
Cylinder number	6
Model	Direct-injection
Diameter mm	110
Stroke mm	120
Compression ratio	17
Displacement L	6.842
Rated output kW/(r·min^{-1})	114/3000

Table 4 Physical and Chemistry Characteristics of Diesel Fuel

Molecular formula	CxHy
Molecular mass	190~220
Density (20 °C) ×10^{3} kg·m^{-3}	0.829
Boiling point °C	180~360
Condensation point °C	-1~3
Flash point °C	65~88
Viscosity mPa·s	3.35
Low heat value MJ·kg^{-1}	42.5
Self-ignition temperature °C	250
Cetane Number	45~50

η_{Rb} is defined as the filter efficiency, and $\eta_{Rb} = \dfrac{Rb_1 - Rb_2}{Rb_1} \times 100\%$, where Rb_1 as the smoke intensity before the filter, Rb_2 as the smoke intensity behind the filter. η_P is regarded as the effective power variation rate of engine as the filter is working, and $\eta_P = \dfrac{P_1 - P_2}{P_1} \times 100\%$, where P_1 as the effective power as the exhaust emits through the by-pass valve, P_2 as the effective power as the exhaust passes by the filter. Δp is though of as the pressure drop of the filter.

4 Experimental Results and Discussion

4.1 Trap Characteristics under Different Rotating Rates

Before the load characteristic test, the engine should rotate according to the setting program so that the lubricant oils are burnt out. Firstly, the engine works at 10% load, 900 r·min^{-1} rate until the oil temperature is up to 60 °C. Then, the engine operates at 50% load, 2000 r·min^{-1} rate until the cooling water temperature is up to 80~90 °C, the lubricant oil temperature 90 °C. Finally, after 5-minute operating, the engine load is added to maximum. At this condition, the engine rotates for 10 minutes so that the engine oils are burnt out. During the experiment, the results are recorded every 0.5 h.

Fig.6 illustrates that the exhaust temperature rises with the loads increasing at the same rate, and increases with the rates improving under the same load. At 2400 r·min^{-1}, the pressure drop of the filter goes up slightly with the loads raising, up to 0.21×10^{5} Pa. While at 1800 r·min^{-1}, it increases apparently with the loads raising, as 0.045×10^{5} Pa under the light loads, and 0.11×10^{5} Pa under full loads.

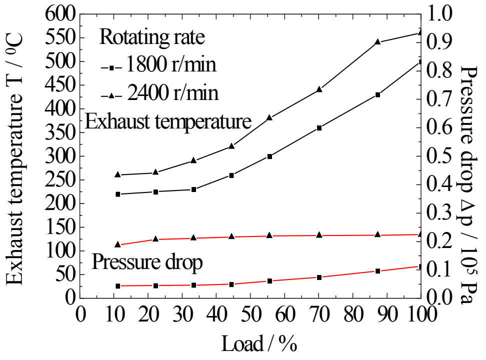

Fig. 6 Exhaust Temperature and Pressure Drop of Filter Changing with Load under Different Rates

Fig.7 discloses that the filtering efficiency alters with the loads under the different rotating rates. At the different speeds, the filtering efficiency is higher under the light and moderate loads, up to 80%~90%. Under the condition of same rate, the filtering efficiency has the falling tendency with the loads increasing. This is because of blowing more filtering particles away by more rapid exhaust with the loads increasing. Under the condition of same load, the filtering efficiency drops with the rates increasing. This is the same reason due to more rapid exhaust blowing effect at the high speed.

4.2 Trap Characteristics under Different Filtering Time

In order to understanding the rule of regenerating time, the test is accompanied at 2000 r·min^{-1}, 50% load. The reason why selecting this operating mode is that 2000 r·min^{-1} is its economical speed, and 50% load the common load. Fig.8 reveals that the filter efficiency and pressure drop of the filter change with the time increasing under this operating mode. And the results are also recorded every 0.5 h.

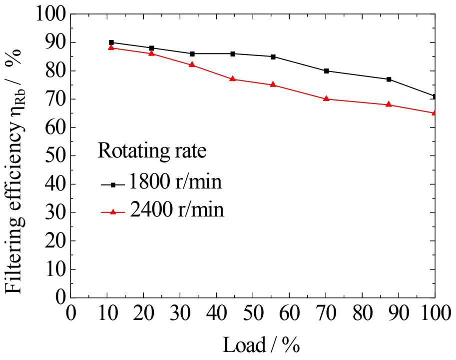

Fig. 7 Filtering Efficiency Changing with Loads Under Different Rates

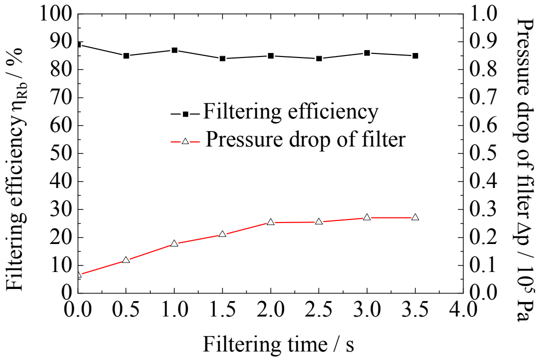

Fig. 8 Filtering Efficiency and Pressure Drop of Filter Changing with Time under 2000 r·min^{-1}, 50% Load

The pressure drop of the filter is 0.065×10^{5} Pa at first, goes up to 0.25×10^{5} Pa linearly by 2h, then increases steadily until 0.27×10^{5} Pa after 3.5h. At this period, the filter efficiency is fluctuating about 90%.

The engine effective power increases about 4.3% as opening the by-pass valve and cutting off the filter valve after 3.5h test. By 15min regenerating, the engine effective power changes no more than 0.66% as turning off the by-pass valve and turning on the filter valve. This illustrates that the particles are exhaustive.

4.3 Trap Characteristics under Full Loads

At full loads, the filtering efficiency grows down due to the rapid exhaust flow. Fig.9 declares the filter efficiency and pressure drop of the filter changing with the rotating rates at full loads. As Fig.9 showed, the filter efficiency decreases with the rates increasing, such as 60%~80% at low speeds, and 50%~60% at high speeds. The pressure drop of the filter increases gradually with the rates improving, i.e., from 0.04×10^{5} Pa at 1200 r·min^{-1} to 0.12×10^{5} Pa at 3000 r·min^{-1}.

Fig.10 illustrates the exhaust temperature and power loss varying with the rotating rates at full loads. Under the full loads, the exhaust temperature goes up with the rates increasing, from 460 °C to 630 °C. And the power loss of the filter is small at low and medium speeds, only 0.198% at 1200 r·min-1 and 0.56% at 2100 r·min^{-1} respectively. Then it increases quickly with the rotating speeds rising, up to 4.5% at 3000 r·min^{-1}. The reason is that the back pressure of exhaust increases very rapidly at high speeds, and the high back pressure results in more effective power loss.

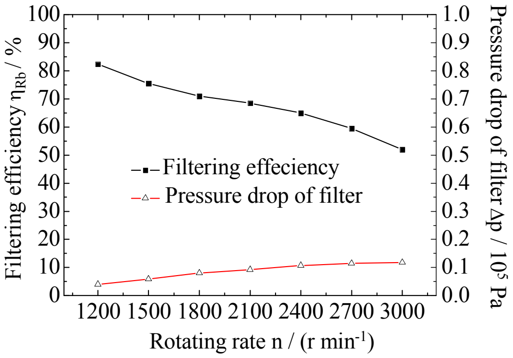

Fig. 9 Filtering Efficiency and Pressure Drop of Filter Changing with Rates under Full Loads

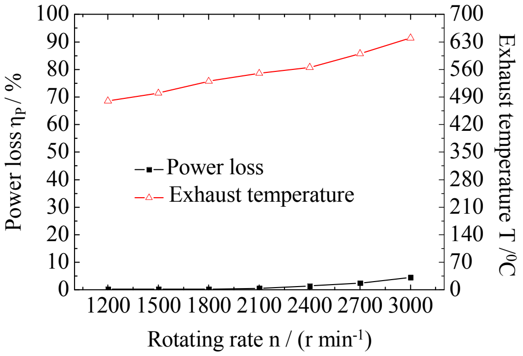

Fig. 10 Exhaust Temperature and Power Loss of Engine Changing with Rates under Full Loads

5 Conclusions

(1) This particle filtering and regenerating trap has relatively simple structure, which uses the honeycomb ceramics and processed wires as the filtering components, and applied the divided-area electrical heating to regenerate the smoke.

(2) This presented filter has 70%~90% filtering efficiency.

(3) The regenerating time of this trap is short, and one of considerations is taking advantage of the promoters to lower the regenerating energy.

References:

[1] Wang Jianxin, Fu Lixin, Li Weibin, *Control of the Pollution from Vehicle Exhaust and Catalyst Installation,* Chemical Industry Press, 2000 (in Chinese)

[2] C.Arcoumanis, L.N.Barbaris, R.I.Crane, et al, *Evaluation of a Cyclone Based Particulate Filtration System for High Speed Diesel Engines*, Proc. Inst. Mech. Eng., 1994, pp. 269~279.

[3] D.B.Kittelson, J.Reinertsen, J.Michalski, *Further Studies of Electrostatic Collection and Agglomeration of Diesel Particles*, SAE Paper 910329, 1991

[4] Takahashi Y, *Apparatus for Engine Exhaust Gas Treatment*, JP: 1119466, 1999210215

[5] Ueno Hideaki, *Development of Catalyst for Diesel Engine*, SAE 980195, 1998

[6] Liu Guanghui, *A Study of Simultaneous Removal of Particulate Matter and NO Using Catalytic Diesel Particulate Filter* [PhD Dissertation], Shanghai Jiaotong University, 2002 (in Chinese)

[7] Hoard, *Plasma-catalysis for Diesel Exhaust Treatment: Current State of the Art*, SAE Paper 2001-01-0185, 2001