The Development of Diesel Particulate Filter Technology

Zhibin Wang*, Peng Liu, Haiming Li, Rui Li, Xiaobing Pan, Yu Zhao
Communication NCO Academy. Army Engineering University. Chongqing, China

*Corresponding author: zhibinwang@aeu.edu.cn

Abstract. With the rapid development of internal combustion engine technology and the widespread popularity of diesel locomotives, the exhaust pollution of internal combustion engines has become a factor that cannot be ignored in air pollution. Particulate matter in diesel engine exhaust is an important culprit in diesel engine exhaust pollution, the harm of which has been widely recognized. This paper introduces the hazards of particulate matter in diesel exhaust, and summarizes DPF for particulate emissions and the regeneration technology of DPF.

Keywords: Diesel engine, DPF, regeneration.

1. Introduction
With the development of economy and the improvement of science and technology, the technology of internal combustion engine has developed rapidly and the number of diesel locomotives has increased year by year. Due to its high compression ratio, diesel engine has the advantages of high thermal efficiency, good fuel economy, good torque characteristics, low emissions, high reliability and long service life. Due to its better economy and power, diesel engine has been widely used in ships, trucks, engineering machinery and other power machinery. Diesel vehicles are playing an indispensable role in the fields of transportation and engineering construction.

With the increase of the number of diesel vehicles, the accompanying exhaust pollution of diesel engine is becoming more and more serious, which has become an important inducement of air pollution.

2. Hazard of particulate matter
The main pollutants in diesel exhaust include nitrogen oxides (NOx) and particulates (PM). The hazards of particulates have been widely recognized and become an important culprit in diesel exhaust pollution.

The particles can be suspended in the air for a long time that can penetrate into the lung lobe through the respiratory tract and adhere to the surface of the lung lobe. The smaller particles can even be absorbed by the blood, causing emphysema, bronchitis and cardiovascular diseases. The soluble organic matter adsorbed on the surface of the particles contains a variety of polycyclic aromatic hydrocarbons (PAH), which has strong carcinogenicity and mutagenicity.

The particulate matter suspended in the air gradually accumulates, which has a greater impact on visibility, increasing the potential risk of transportation. Particles in the air are easy to form PM2.5. Because of its small particle size, rich in a large number of toxic and harmful substances, long stay
time in the atmosphere, long transportation distance and even haze in serious cases, it has a greater impact on human health and atmospheric environment.

The survey shows that motor vehicle exhaust emissions are an important source of PM2.5. The inclusion of PM2.5 in monitoring indicators will directly accelerate the process of upgrading our country's emission regulations. Therefore, strict control of diesel engine particulate emissions has become a top priority.

3. The diesel particulate filter technology

The diesel particulate filter is abbreviated as DPF, which is currently recognized as the most effective and relatively mature device for realizing diesel particulate emission control. When the exhaust gas passes through the particulate filter, the particulate is first collected by the element of the particulate filter, and then the particulate collected by the filter will be oxidized and burned to complete the regeneration of the filter. The particulate filter is mainly composed of filtering device, regeneration device and control device, the key technology of which is the selection of filter materials and the regeneration of the filter. At present, there are mainly the following filters that have been studied at home and abroad.

3.1. Ceramic fiber filter

The high temperature resistance of ceramic fiber is strong, while it is not limited by the specific size when it is manufactured. In concrete use, the shape and distribution of the holes in the filter cavity can be selected according to the need, at the same time, the application effect can be optimized by changing the design parameters of the ceramic fiber materials. Since the surface of the ceramic fiber is a good filtering surface, the filtering efficiency of the ceramic fiber materials is generally very high. The catalyst can be added to the ceramic fiber materials. Ceramic fiber filter is generally made into felt. The disadvantage of the ceramic fiber filter is that the ceramic fiber materials is relatively brittle, easily damaged during processing and use. When the engine exhaust gas flow rate and exhaust gas temperature fluctuate greatly, it is easily broken and damaged. In order to improve its mechanical strength, the ceramic fiber materials can be alternately woven with the wire mesh, which serves as a skeleton, but the production process is relatively complicated. Another disadvantage is that it is not suitable for cleaning and can’t be regenerated and reused, so the utilization efficiency is low.

3.2. Wire mesh filter

The wire mesh filter was first produced by GM and used to capture particulate matter emitted by diesel engine. The filter made of wire mesh has a smooth surface and small specific area, so the filtration efficiency of this collector is low, only about 20% to 50%. In order to increase the filtering efficiency, a corona charging device can be added in front of the filter to charge the particulates, while the metal mesh can also be woven together. The advantage is that the pores inside the filter are evenly distributed and are easy to particulate, while the metal wire mesh has good conductivity and good capture performance for charged particles. The metal wire mesh filter also has good high temperature resistance and seismic resistance, so it has a longer life and lower cost.

3.3. Foam ceramic filter

The internal structure of the foam ceramic is similar to the foam plastic, the interior of which is filled with tiny holes communicating with the adjacent hole. When the exhaust gas of the diesel engine passes through the filter, the particulate matter in the exhaust gas will be partially deposited in the small holes. The filtration efficiency of the foam ceramic filter is low, generally only 40% to 60%, but the foam ceramic is beneficial to regeneration due to its internal structure, during which the flame is easy to propagate through the interconnected pores. The foam ceramic parameter is isotropic and the thermal stress coefficient is small, so the filter will not be damaged during regeneration. The disadvantage is that the structural strength is low and it is easy to be damaged during exhaust shock and mechanical vibration.
3.4. Wall-flow filter

The wall-flow filter filters the particulate matter in the exhaust gas through the small hole wall surface. The small holes on both ends of the filter are blocked. Diesel exhaust gas enters from the open small hole at one end of the filter, entering the adjacent small hole through the wall surface of the small hole because the small hole is already blocked at the other end. The adjacent small hole is open at the other end of the filter so the exhaust gas can be discharged into the atmosphere from the opening. In this process, the exhaust gas particulate matter is filtered and trapped by the walls of the small holes. The wall-flow filter also has the characteristics of high filtering efficiency, low exhaust resistance, good high temperature resistance, high mechanical strength, excellent corrosion resistance and good thermal shock resistance, especially suitable for working in the exhaust environment of diesel engine.

Compared with other filters, the wall-flow filter is currently recognized as the filter with the best overall performance and the most extensive research and application abroad. At present, more materials used for wall-flow filter are cordierite and SiC.

4. The development of DPF regeneration technology

Particulate filter can effectively reduce diesel particulate emissions, which are deposited more and more in the filter as the mileage increases, resulting in increased exhaust backpressure and deterioration of the engine's economy and power. The collected combustible particles must beoxidized and burned in time to realize the regeneration of the particle filter.

In the early days of the development of particulate filter, the offline regeneration method was used to solve the regeneration problem, which has certain effect for diesel engine with a sufficiently long regeneration cycle, but the practicability is poor. In recent years, with the widespread use of particulate filter, a lot of meticulous research work has been carried out on diesel particulate filter regeneration technology at home and abroad, proposing various regeneration technologies.

4.1. Catalytic regeneration method

The catalytic diesel particulate filter is coat or impregnate the catalyst with high catalytic activity on the surface of the filter element material. Catalytic regeneration uses chemical catalysis to reduce the reactive activation energy of the particles, so that the particles can be burned under the normal exhaust temperature of the diesel engine to achieve regeneration [1]. Some catalysts can reduce the ignition temperature of particles by 200°C to 300°C, depending on the formulation of the catalyst. As long as the exhaust gas reaches a certain temperature, the energy of the exhaust gas can be used for regeneration. In this way, regeneration is easy to achieve, saving the energy required for regeneration and simplifying the regeneration control system, while the engine maintains low exhaust back pressure operation with low regeneration energy consumption. During the regeneration process, the heat load on the filter is small, which improves the life and reliability of the filter. The focus of research is to find a more effective catalyst, so that the particles can be ignited at the lower temperature, at the same time the emissions of other harmful gases should be taken into account. Since the contact reaction between the particles and the catalyst is extremely uneven, it is difficult to perform complete regeneration. Over time, the role of the catalyst will gradually decrease or disappear completely, thereby affecting the effective regeneration of the filter and the catalytic purification of other harmful gases. This type of technology requires the sulfur content of the fuel to be below 150 ppm to avoid catalyst poisoning caused by high diesel sulfur content.

4.2. Electrical heating regeneration method

The electrical heating regeneration technology directly uses the energy of the vehicle power supply to generate heat to increase the temperature of the engine exhaust and burn the particulate matter in the DPF, thereby achieving DPF regeneration [2]. Automobile companies in the United States and Japan have developed related products in the 1990s and used them in trucks and buses. The equipment and control method used in the electrical heating regeneration method is relatively simple, easily to realize the regeneration of the DPF, but a large amount of electrical energy needs to be consumed in a short
time when using this method for regeneration, which puts high requirements on the vehicle battery. The regeneration method can be divided into two types that are front-end heating and DPF internal heating. The front-end heating method consumes a large amount of power, while the regeneration method of DPF internal heating is likely to cause uneven

4.3. Microwave heating regeneration method
The microwave heating regeneration appeared in the early 1990s, the remarkable feature of which is the selectivity and uniformity for the heating of particles. The ceramic material filter has poor microwave absorption capacity, but the particles have strong microwave absorption capacity, which is more than 100 times of ceramics [3]. Therefore, when microwave heating is used, the particles are the main object to be heated, improving the energy utilization rate, extending the life of the filter, and also improving the regeneration efficiency. Moreover, the microwave energy is spatially distributed in the filter, during regeneration, the entire filter is heated and the temperature gradient in the filter is small, which reduces the possibility of thermal stress damaging the filter. In this way, the particles deposited inside the filter body can absorb heat and burn on the spot, without any form of combustion propagation. The disadvantages of this technology are that the microwave heat release rate is fast, the regeneration process is difficult to control, and a safety problem of microwave leakage exists.

4.4. High-load regeneration method and throttle regeneration method
The high-load regeneration method and the throttle regeneration method are the most direct and simple regeneration methods. When the diesel engine is under large load, intake throttle and exhaust throttle conditions, its exhaust temperature will increase significantly. When it reaches the ignition point of particulate matter, the particulate matter in the DPF will start to burn to achieve DPF regeneration. This regeneration method completely uses the own special working conditions of the engine to achieve DPF regeneration, so it is mostly suitable for high-power diesel engine working in fixed locations. On-board diesel engine can’t use this regeneration method because it is difficult to achieve high-load conditions that meet the requirements. When the diesel engine is under heavy load, intake throttle and exhaust throttle conditions, the thermal load of important components such as pistons, cylinder heads and valves of the diesel engine is very high, so this regeneration method will reduce the service life of the diesel engine [4].

4.5. Continuous regeneration method
The continuous regeneration method is a kind of inactive regeneration method, under which capture and regeneration are simultaneously carrying [5]. The regeneration method mainly relies on a special oxidation catalytic converter to dislodge the particles in the exhaust gas and DPF, which can directly dislodge part of the particles in the exhaust gas. When the nitrogen oxide in the exhaust gas passes through the converter, part of the nitric oxide will react with the oxygen under the action of the catalyst to generate nitrogen dioxide that has a strong oxidation ability, which can oxidize the particles in DPF in a lower temperature range and realize the continuous regeneration of particles. Foreign research companies have done a lot of work on the regeneration technology and have launched relevant products, which have good effect. However, because the requirements of diesel oil quality are very high, the quality of domestic diesel oil is difficult to meet the use requirements of the regeneration method.

4.6. Reverse blowing regeneration method
The reverse blowing regeneration method is a regeneration method close to the pure physical method, which can also be called the reverse airflow regeneration method [6]. The regeneration method uses high-pressure air flow to blow in a spiral circle from the rear end of the DPF, blowing the particulate matter captured by the DPF into a pre-prepared container to achieve DPF regeneration. The greatest advantage of this regeneration method is that there is no high temperature or severe temperature fluctuation during the regeneration process, so it will not cause thermal damage to the DPF.
regeneration method also has its own shortcomings. Firstly, it needs to be equipped with a compressed air machine and a compressed air storage tank, which requires a large space. Secondly, high-pressure air during the regeneration process will damage the DPF plug, so long term use of this regeneration method may lead to the reduction of DPF capture efficiency.

4.7. Fuel injection combustion-supporting regeneration method

Foreign researchers and domestic Chery companies have studied the fuel injection combustion-supporting regeneration method. This method can be used on the direct injection diesel engine that uses a common rail fuel injection system, which fully utilizes the advantages of the common rail fuel supply system to achieve multiple injections and achieves post-injection of fuel. When the regeneration timing is mature, a small amount of diesel is injected into the cylinder at the end of the power stroke, using the high-temperature and high-pressure environment in the cylinder to burn the diesel injected afterwards, so that the temperature of the exhaust gas discharged during the exhaust stroke is relatively high. The high-temperature exhaust gas enters the DOC, which makes hydrocarbons and carbon monoxide further oxidize to exothermic heat and increase the exhaust temperature, so as to realize the regeneration of the filter and reduce the secondary pollution. The entire regeneration process is controlled by the ECU of the car, which is carried out by the driver without feeling [7]. The optimal regeneration distance of this method is 400km, when the deterioration of fuel economy is more serious. This method requires higher engine control technology, while the long-term use will affect the service life of the engine.

The popularization and application of diesel particulate filter mainly depends on the development of regeneration technology. At present, there are many problems in regeneration technology, such as poor fuel quality, poor battery performance, complex equipment and high cost. But with the development of regeneration technology, diesel particulate filter will be widely used.

5. Conclusions

DPF technology has been widely used and deeply studied as one of the most effective methods to control diesel exhaust emissions. With the development of diesel engine emission regulations, the requirements of emission regulations on diesel engine exhaust emissions are increasingly strict, which is conducive to reducing air pollution. With the increasing demand for diesel engine in transportation and engineering construction, DPF technology will have a broad prospect.

References

[1] F. Piscaglia, G. Ferrari, A novel 1D approach for the simulation of unsteady reacting flows in diesel exhaust after-treatment systems, Ener. vol. 84, 2008, pp. 1-12.
[2] E. Bissett, Mathematical Model of the Thermal Regeneration of a Wall-Flow Monolith Diesel Particulate Filter, Chem. Eng. Scien. vol. 39, 1984, pp. 1232-1244.
[3] D. Wang, Study on Diesel Particulate Filter and Its Regeneration Technique, Changchun:Jilin University, June, 2013.
[4] F. Wang, X. Guo, Y. Ma, Research status and development trend of diesel exhaust particulate filter technology, Smal. Inter. Com. Eng. and motor. vol. 39, 2010, pp. 92-96
[5] Q. Su, W. Liu, J. Chen, Experimental study on nitrogen dioxide continuous regeneration diesel particulate trap, Jour. of inter. Com.n eng. vol. 19, 2001, pp. 443-446
[6] Y. Shao, Study on reverse jet regeneration technology of diesel particulate filter, Tianjin: Tianjin University, March 2005
[7] C. Zhang, D. Jiang, X. Zi, Study on gas regeneration technology of diesel engine exhaust particulate filter, Jour. of inter. Com. Eng. vol.20 2002, pp. 391-394