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# PM EMISSION FROM DIESEL ENGINES AND DPF TECHNOLOGY

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**ABSTRACT**
Diesel engines are among the most widely used power supplies in both transportation and industrial/energy fields. High durability, high efficiency, low fuel consumption are the features that make diesel engines advantageous. However, in addition to these superior properties, they contain high levels of Nitrogen Oxide (NOx) and Particulate Matter (PM) emissions in the exhaust contents, which cause great environmental problems. Diesel engines are one of the leading sources of air pollution and global warming due to their pollutant emissions (especially NOx and PM). This study deals with PM emissions generated by diesel engines and Diesel Particulate Filter (DPF) technology used to eliminate these emissions. In this study, formation of PM emissions, negative effects on human health and environment, DPF technology, history of DPF technology and recent developments in DPF technology have been examined in detail. The results are showed that diesel engines have a significant contribution to the formation of PM emissions, PM emissions cause serious damage on human health and environment, the elimination of PM emissions is a necessity, various policies and standards are developed to prevent PM emissions. DPF technology is clearly the most effective method for removing of PM emissions and PM emissions can be eliminated at very high rates thanks to DPF technology.

***Keywords:*** *Air Pollution, Particulate Matter, Pollutant emissions, Diesel Engine, Diesel Particulate Filter*

## 1. INTRODUCTION

Air pollution is one of the major problems on the agenda of many countries. Because of the air pollution, both the human health and environment are under great danger. The heavy consequences of air pollution have become undeniable. According to the report prepared by the World Health Organization, approximately 7 million people die every year due to air pollution (World Health Organization, 2014). There has also been an increase in natural events (tsunamis, floods, heat waves, storms, tornadoes, etc.) around the world.

PM emissions are one of the most important pollutant emissions causing air pollution. PM emissions directly or indirectly affect air visibility adversely, short the visibility, cause acidification, and even threat the human health by accelerating virus transfer. It is widely known that these carcinogenic emissions cause premature deaths. Air pollution caused by pollutant emissions, particularly PM emissions, has been reported to cause an average of 3.3 million premature deaths annually worldwide (Lelieveld et al., 2015). Heart failure, lung cancer, respiratory distress, respiratory diseases are important health problems caused by PM emissions (Smith et al., 2019; Pope et al., 2006;). At the same time, significant evidence has been obtained that PM emissions are associated with Type 2 diabetes and that obesity, systemic inflammation and Alzheimer's disease occur in people with Type 2 diabetes (European Environment Agency, 2018). Although many efforts are being made to reduce PM emissions worldwide, it is obvious that many people are exposed to these emissions at a high level.

The economic impact of PM emissions on countries has also reached considerable levels. The loss of work caused by premature deaths, the treatment of health problems caused by PM emissions, and the elimination of environmental damage are consuming a large part of the budget of the country (European Environment Agency, 2018).

The majority of PM emissions are generated from energy production. Diesel engines, which are widely used in the transportation and other sectors (industry, energy, agriculture etc), are the leading sources of PM emissions.

As the negative effects of PM and other pollutant emissions become widespread day by day and can be noticed by everyone, high efforts are being made to control these emissions. Many research and development (R&D) activities have been carried out in order to reduce these emissions in many areas, especially in the transportation sector, policies have been established and various limitations and standards have been promulgated. Research and development activities to ensure the elimination of pollutant emissions from vehicles have focused on aftertreatment emission control technologies. Diesel Oxidation Catalyst (DOC) for CO and HC emissions, Selective Catalytic Reduction (SCR) for NOx emissions and Diesel Particulate Filter (DPF) for PM emissions were developed and adapted to vehicles.

In this study, the formation and effects of PM emissions from diesel engines, the factors affecting the formation of PM emissions, DPF technology used to control PM emissions and the latest developments in DPF technology are explained in detail.

## 2. PM EMISSIONS FROM DIESEL ENGINES

High efficiency and durability compared to gasoline engines have made diesel engines usable in many sectors. However, PM emissions from diesel engines are one of the most important problems that may prevent the use of diesel engines (Maricq, 2007). Diesel engines emit higher PM emissions compared to gasoline engines. Certainly, diesel engines are among the top sources of PM emissions.

PM emissions with complex microstructures are composed of element and organic carbons, sulphate, ash, nitrate, water, metal oxides and other components (Sharma et al., 2012). In an experimental study, the particulate matter content of a diesel engine used in a heavy-duty vehicle was determined as 41% carbon, 7% unburned fuel, 25% unburned oil, 14% sulfate and water, 13% ash and other components (Kittelson, 1998). The chemical structure of PM emissions plays an important role in human health and the environment.

Diesel particulate matter generally consists of 15-40 nm spheres and approximately 90% of the particulate matter is less than 1 μm in diameter. The formation of PM emissions varies depending on many parameters such as combustion and expansion time, fuel quality (sulfur and ash content), quality and consumption of lubricating oil, combustion temperature and exhaust gas temperature.

Standards are set for PM emissions from diesel engines. These standards are tightened with each passing time and the permissible PM emission values in the exhaust gas content are lowered. Figure 1 presents the Euro Standard values for PM emissions for heavy duty vehicles. Euro standards first came into force in 1993 and a limit of 0.61 g/kwh was imposed on PM emissions. In the Euro VI standard which has been in force since 2013, this value is determined as 0.01 g/kWh. This situation shows that the accepted value of PM emissions decreased by 98.36% in 20 years.

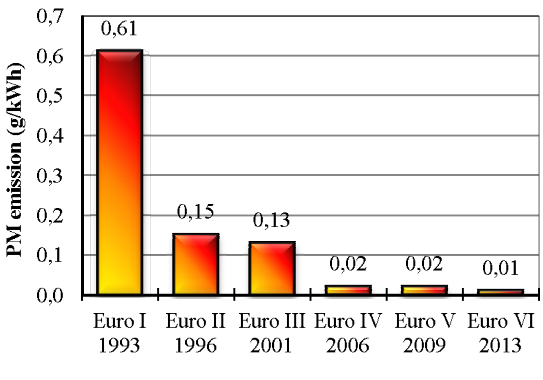


Fig. 1. Euro standards of PM emission for heavy-duty vehicles (Delphi, 2019)

The serious tightening of Euro standards for PM emissions has led many researchers, especially automotive manufacturers, to produce alternative solutions. Although significant reductions in PM emissions have been achieved with engine modifications, the development of electronically controlled fuel injection systems, improved fuel properties, and the use of alternative fuels such as biodiesel and alcohols, the desired PM emission values have not been achieved

(Vaughan et al., 2019; Fiebig et al., 2014). Thanks to the DPF technology developed as a result of the ongoing research, the values determined by the standards have been reached and the damage caused by PM emissions from diesel engine has been prevented to a great extent. DPF technology has become the center of attention especially with the Euro V standard effectuated in 2009 (Tzamkiozis et al., 2010).

## 3. DIESEL PARTICULATE FILTER (DPF)

DPF technology, one of the aftertreatment emission control systems, is widely used in today's diesel vehicles. Thanks to DPF, PM emissions can be eliminated at very high rates (over 90%) (Maricq, 2007). DPF on the exhaust system, which is usually made of Silicon Carbide material, acts as a filter to trap PMs in the exhaust gas content. Although the first foundation of the DPF was laid in 1969 and developed in 1978-1994, its application to vehicles was realized in the 2000s (Dittler, 2017). DPF technology was developed by tightening the restrictions on PM emissions in Euro standards.

High temperature resistance, extreme resistance to thermal stresses, corrosion resistance and mechanical strength characteristics are the factors that are considered in the selection of DPF materials. DPF is generally produced in silicon carbide (SiC), cordierite ($2MgO\text{-}2Al_2O_3\text{-}5SiO_2$) or metal structure which can provide these properties. Among these structures, SiC is most commonly used.

DPF generally has a high number of porous and parallel channels with square geometry. The channel wall thickness is generally in the range of 300 to 400 μm. Channel dimensions are determined by the number of pores. The number of pores commonly used in these filters varies between 100-300 cpsi.

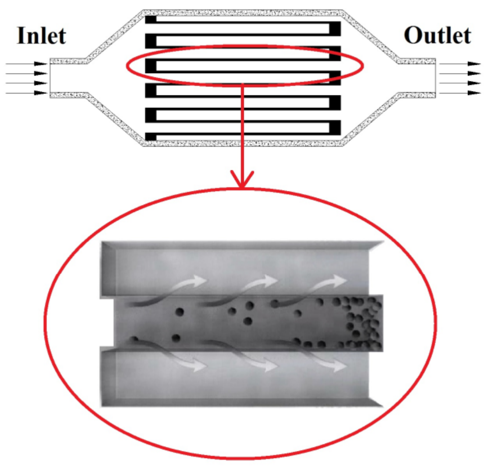


Fig. 2. The structure of Diesel Particulate Filter (DPF)

Figure 2 presents the structure of the DPF visually. DPF simply consists of several monolithic pores whose inputs and outputs are mutually closed. Since the pore outlet of the exhaust gas entering the pore is closed, it provides a flow from the pore walls to the other pores around it. During the flow through the pore walls, PM emissions are filtered in these walls. This filtering continues until the DPF filtering capacity is full. After the DPF is filled with PM emissions and clogged and an increase in pressure occurs in the exhaust system, regeneration is carried out to remove PM emissions on the DPF. Regeneration is the most emphasized process in DPF technology and many research and development activities are currently being conducted on this process (Ko et al., 2016; Dwyer et al., 2010).

The regeneration process is the combustion of the PM emissions absorbed in the DPF. Combustion is carried out by oxidation of PM emissions. Compared to $O_2$, the oxidation process carried out with $NO_2$ in the exhaust gas content reduces the combustion temperature of PM emissions and increases the regeneration efficiency. Although the temperature required for the combustion of PM emissions is above 500 °C, this value can be lowered depending on the amount of $NO_2$ contained in the exhaust content. Thanks to a Diesel Oxidation Catalyst used downstream DPF, a significant proportion of NO in exhaust gas content are converted to $NO_2$ (Lizarraga et al., 2011). The exhaust gas from the diesel engine reaches DPF after passing through the DOC. In the meantime, NO in the exhaust gas content is converted to $NO_2$ and is directed to DPF. The higher $NO_2$ content in exhaust gas content lower the PM ignition temperature (Jiao et al., 2017). At the same time, the exhaust gas content, the exhaust flow, the fuel used and the physical and chemical properties of the PM emissions affect the regeneration efficiency (Rodriguez et al., 2017).

Regeneration process is realized in two different ways as active and passive. The temperature increase in active regeneration is provided by an extra energy source. This energy source is generally a fuel produced specifically for this process. Fuel is burned by spraying on the exhaust at the inlet of the DPF and the temperature of the DPF is increased accordingly to ensure the combustion of PM emissions (Chen et al., 2014). Apart from the additional fuel injection, the energy source required can be provided by electric heaters or microwave beams (Pallavkar et al., 2009). Active regeneration is carried out in vehicles between 300-800 km intervals (Beatrice et al., 2017).

In the passive regeneration process, no external energy source is needed. The increase of the DPF temperature is achieved by loading the engine. When a blockage is detected in the DPF system, the engine is operated at high speeds and load to increase the exhaust gas temperature, thereby increasing the DPF temperature and burning PM emissions to the outside. Passive regeneration prevents the burning of extra fuel and extends the life of the DPF (Soltani et al., 2018). Thanks to DOC used before DPF, the formation of $NO_2$ which provide oxidation of PM emissions is provided. Thanks to DOC, which converts the NO emissions to the $NO_2$, oxidation temperatures of PM emissions can be reduced.

The most important issue in DPF technologies is the proper regeneration process. Failure to perform the regeneration process causes problems in the engine and exhaust system. Engine traction may drop and even the engine may stop due to excessive pressure increase in the exhaust system. For this reason, regeneration must be carried out regularly. The quality of the fuel used is one of the most important parameters affecting the regeneration. Fuel that does not comply with the standards can lead to serious damage to both the DPF and the engine.

## 4. CONCLUSION

It is obvious that PM emissions cause very serious damage to the environment and human health. Diesel engines, which are used in many different sectors, especially in the transportation sector, are one of the most important sources in the formation of PM emissions. In order to prevent PM emissions from diesel engines, many regulations and standards are put into force. The PM emissions allowed by these standards can be achieved through DPF technology, which is one of the most widely used aftertreatment emission control technologies in diesel engines. Thanks to DPF, PM emissions can be eliminated at very high rates. Regeneration is the most important process in DPF technologies. Regeneration process can be active or passive. Passive regeneration offers significant advantages compared to active regeneration. Research on DPF technology will continue. Particularly, thanks to the nowadays catalyst-containing DPF technology, higher conversion performances can be achieved by increasing the DPF efficiency. At the same time, the use of alternative fuels with DPF can be an effective method of achieving the desired PM emission values.

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