ENVIRONMENTAL POLLUTION BY DIESEL ENGINES. PART II: A LITERATURE REVIEW REGARDING HC, CO, CO₂ AND SOOT EMISSIONS

Oana ZBARCEA, Dan SCARPETE, Vlad VRABIE

“DUNĂREA DE JOS” UNIVERSITY OF GALATI, Romania

Abstract. Compression ignition engines (CI) engines generate undesirable emissions during the combustion process, and the main pollutants produced from the exhaust of IC engines are hydrocarbon (HC), nitrogen oxides (NOₓ), particulate matter (PM), black smoke, carbon monoxide (CO), and carbon dioxide (CO₂). This paper aims to review some literature data about HC, CO, CO₂ emissions, and soot formation from diesel engines, for having a more clear perspective on the main exhaust harmful for the environment. Diesel engines offer the possibility of combining very high thermal efficiencies with very low emissions, and their good fuel efficiency results in low CO₂ emissions. Very high temperatures in the combustion chamber help reduce the emission of soot but produce higher levels of NOₓ emission. Driving tests on chassis dynamometer showed that HC emissions for a diesel passenger car and a truck have reached a minimum at a vehicle speed of 50 km/h. HC emissions depend on the vehicle load, the higher load, the lower level of HC emissions.

Keywords: diesel engines, emissions of HC, CO, CO₂ and soot, environment.

1. INTRODUCTION

Diesel engines have provided power units for road transportation systems, ships, railway locomotives, equipment used for farming, construction, and in almost every type of industry due to its fuel efficiency and durability [1].

The diesel engine offers superior fuel and thermal efficiencies, greater power output, superior torque and better durability compared to the spark ignition engine. On the other hand, the diesel engine is a major source of both criteria and non-criteria air pollutants, which contribute to the deteriorating air quality [2].

The emissions produced (Table 1) due to the operation of diesel engine with diesel are highly responsible for several critical problems issues to develop a more efficient engine with less environmental impact [3].

![Table 1. Constituents of Internal Combustion Engine Exhaust Gases [4]](image_url)

Diesel emissions contribute to the development of cancer, cardiovascular and respiratory health effects, pollution of air, water, and soil, soiling, reductions in visibility, and global climate change [5].
This paper presents a review on the four main pollutant emissions from diesel engines. In this context, HC, CO, CO₂ and soot emissions are detailed individually.

2. HC FORMATION, CHARACTERISTICS AND EFFECTS

HC are unburnt fuel components which occur in the exhaust emissions after incomplete combustion [6]. Diesel engines normally emit low levels of hydrocarbons. Diesel hydrocarbon emissions occur principally at light loads. The major source of light-load hydrocarbon emissions is lean air–fuel mixing. In lean mixtures, flame speeds may be too low for combustion to be completed during the power stroke, or combustion may not occur, and these conditions cause high hydrocarbon emissions [3, 7].

A schematic representation of diesel hydrocarbon formation mechanism, for fuel injected while combustion is occurring is shown in Figure 1 [8].

![Figure 1. Schematic representation of diesel hydrocarbon formation [8].](image)

Hydrocarbons (HC) occur in a variety of forms (e.g. C₆H₆, C₈H₁₈) and each has different effects on the human organism. Some hydrocarbons irritate the sensory organs while others are carcinogenic (e.g. benzene) [6].

Hydrocarbons have harmful effects on environment and human health. With other pollutant emissions, they play a significant role in the formation of ground-level ozone. Vehicles are responsible for about 50% of the emissions that form ozone. Hydrocarbons are toxic with the potential to respiratory tract irritation and cause cancer [9].

3. CO FORMATION, CHARACTERISTICS AND EFFECTS

CO is a toxic and harmful air pollutant. It is colourless, odourless, explosive and highly toxic. Even a relatively low concentration of carbon monoxide in the air we breathe is fatal.

An estimate has shown that vehicular exhaust contributes about 64% of the CO pollution in developed countries [6, 11]. Carbon monoxide is majorly a product of incomplete oxidation of the fuel carbon content in fuel rich zones as consequence of fuel-air ratios [12].

CO emission formation is one of the principal reaction in the hydrocarbon combustion mechanism, are [13]:

\[ RH \rightarrow R \rightarrow RO_2 \rightarrow RCOH \rightarrow RCO \rightarrow CO \]  

where \( R \) stands for the hydrocarbon radical.

CO emissions increase exponentially with decreasing speeds (Fig. 2) [14].

![Figure 2. Variation of CO emission (g/km) versus car speed (km/h) (adapted from [14]).](image)

Nevertheless, due to a resultant low combustion temperature, HC and CO emissions rise significantly, especially at low load when the catalyst bed temperature is not sufficient for their aftertreatment [15]. The factor of 2 increase in CO emissions observed during higher-speed uphill driving is likely evidence of enriched engine fuel/air ratios; this was unexpected because uphill driving observed in this study occurred at moderate engine loads within the range experienced during the city driving cycle of the U.S. emissions certification test [15].

Emissions of carbon monoxide (Fig. 3) in general decreased from 1981 to 1998, mainly owing to the introduction of three-way catalysts. This trend is expected to continue [16].

Breathing the high concentrations of CO typical of a polluted environment leads to reduced oxygen
(O₂) transport by hemoglobin and has health effects that include headaches, increased risk of chest pain for persons with heart disease, and impaired reaction timing [17].

4. CO₂ FORMATION, CHARACTERISTICS AND EFFECT

Atmospheric CO₂ is produced both from natural sources and from human activities. Of human activities, the most important source of CO₂ is the release during the consumption of fossil fuel [14].

CO₂ is a colourless, non-flammable gas. It is produced by the combustion of fuel containing carbon (e.g. petrol, diesel). Carbon combines with oxygen induced into the engine [6].

The CO and CO₂ emissions were consistently higher for petrol engines as compared to diesel engine vehicles (Fig. 4) [18].

The reason for lower emissions of CO and CO₂ for diesel engines may be due to the use of compression ignition technology as opposed to spark ignition technology of petrol engines which provided for complete combustion of fuel [18].

Diesel engines are generally more efficient than petrol engines (they have a higher compression ratio, and diesel fuel also contains more energy per unit volume), and they produce lower levels of CO and CO₂ emissions per kilometre travelled [19].

Two sectors play a pivotal role in the continued growth at global CO₂ emission: power generation and road transport (Fig. 5) [20].

At global level, both sectors had consistently similar annual growth rates of 5% per year in the seventies [20].

CO₂ is considered to be a potential inhalation toxicant and a simple asphyxiate. It enters the body from the atmosphere through the lungs, is distributed to the blood, and may cause an acid-base imbalance, or acidosis, with subsequent CNS depression. Acidosis is caused by an overabundance of CO₂ in the blood [21].
5. SOOT FORMATION, CHARACTERISTICS AND EFFECTS

Soot is a carbonaceous particulate matter and is produced during combustion of the rich fuel-air mixtures. Appearance of black smoke emissions in the exhaust indicates high concentration of soot in the exhaust gases. Soot is mostly produced in the diffusion combustion systems, but overly rich premixed combustion also produces soot [22].

As the spark ignition engines generally operate close to stoichiometric air-fuel ratio, soot emissions from these engines are not significant. With the use of unleaded gasoline, lead particulates from the SI engines have been eliminated [22].

The formation manner of soot on diesel engines, during quasi-steady portion of combustion is shown in Figure 6 [23].

When fuel jet penetrates into the cylinder, it carries hot air from surrounding cylinder gases, forming a cone-shape spray (black region). The actual jet contains a higher concentration of fuel along the centerline with lower concentration around the perimeter, which is illustrated by a thin line white region, just outside the black liquid fuel region [23].

The combustion products are entrained into the jet, downstream of the location where the diffusion flame starts. The rich combustion products continue to move down stream and diffuse toward the surrounding diffusion flame [23].

Typical particle composition of a heavy-duty diesel engine tested under a heavy-duty transient cycle breaks down as follows: carbon 41%; unburned fuel 7%; unburned oil 25%; sulphate and water 14%; and ash and other components 13% as shown in Figure 7 [24].

Depending on engine design and operating conditions and fuel composition the fraction associated with unburned fuel and lube oil, generally described as the soluble organic fraction (SOF) may vary widely.

Soot emissions have been associated with respiratory problems and are thought to be carcinogenic in nature. The particle size is important as the particles smaller than 2.5μm can reach lungs along with the inhaled air and cause health problems. The particles smaller than 2.5 μm constitute more than 90% mass of the total particulate matter in the diesel exhaust [22].

6. CONCLUSIONS

This article reviews the characteristics of main pollutant emissions (HC, CO, CO₂, and soot) from diesel engines and control technologies of these pollutant emissions with standards and regulations.

These pollutant emissions have harmful effects on environment and human health.

Atmospheric concentrations of carbon dioxide (CO₂) and other so-called greenhouse gases continue to rise, the earth’s climate will become warmer. Emissions of CO₂ caused by human activity are generally considered the most important single source of potential future warming.

Key climate processes (in particular, warming the deep ocean) involve long lags, and important greenhouse gases (in particular CO₂) remain in the atmosphere for many years after they are emitted.

REFERENCES


