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Experimental investigations of heavy metal addition in lubricating oil and soot deposition in an EGR operated engine

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Abstract

Exhaust gas recirculation (EGR) is a technique, which is being used widely to reduce and control the NO_x emissions from diesel engines. However, the use of EGR leads to rise in soot emission because of soot–NO_x trade-off. This EGR generated soot leads to several other problems inside the engine like degradation of lubricating oil, enhanced engine wear etc. In the present study, an experimental investigation has been carried out to evaluate the effect of EGR on characteristics of lubricating oil with time of its usage.

A two cylinder, air cooled, constant speed direct injection diesel engine of 9 kW rating was used for conducting the experiments. The experiments were conducted in two phases for a comparative study on the normally operated engine (i.e. without EGR) and the engine operated with EGR for 96 h in each phase. Lubricating oil samples were collected after every 24 h interval and were analysed for soot loading (total carbon content) and various metal addition due to wear of the engine. Higher metal contents were found in the lubricating oil drawn from the engine using EGR. Higher carbon deposits were also observed on vital parts of the engine operating with EGR.

Keywords: EGR; Heavy metals; Soot; Engine wear; Lubricating oil

1. Introduction

In recent years, popularity of diesel engines has increased due to its higher fuel economy and low maintenance cost. At the same time, regulatory emission norms around the world have been tightened in order to control the emissions from vehicles. For diesel engines, these norms particularly focus on emission of oxides of nitrogen (NO_x) and particulates. NO_x is primary as well as secondary pollutant. These gases are toxic to human nervous system apart from being responsible for smog formation in the environment [1]. They react with the volatile hydrocarbons to form troposphere ozone, which is a major pollutant in smog. For controlling the emission of NO_x from diesel engines, various techniques have been tried e.g. retarded injection timing, injection of diluents in combustion chamber, selective catalytic reduction, NO_x adsorbers, exhaust gas recirculation (EGR) etc. Most of these techniques have limitations in practical implementation on the engines. EGR has proved to be an effective method of reducing NO_x emissions and is practically implemented in most diesel engines worldwide. In EGR system, part of exhaust gas is recirculated and mixed with air in the intake manifold, replacing an equal amount of fresh air. This reduces the availability of oxygen and increases the heat absorbing capacity of the exhaust gas and air mixture entering the combustion chamber, since specific heat of exhaust gas is significantly higher than air. The oxygen in air is partially displaced by CO_2 and water vapour of the exhaust

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gases, thus reducing oxygen to fuel ratio. The reduction in oxygen availability in the combustion zone leads to lower flame temperature. This effectively leads to reduced NO_x formation [2]. The rate of nitric oxide (NO) formation is highly dependent on temperature and decreases with lowering of the temperature and availability of oxygen [3]. Thus combination of increase in specific heat and reduced oxygen in intake air reduces the flame temperature which controls the rate, at which NO_x formation reactions proceed [4]. However, studies have shown that particulate matter (PM) emission increases consistently as the EGR rate increases [5,6].

The EGR rate is given by the following equation:

$$\mathrm{EGR}\% = \frac{V_{\mathrm{EGR}}}{[V_{\mathrm{Air}} + V_{\mathrm{EGR}}]} \times 100$$

where, V_{EGR} = volume of recirculating exhaust gas; V_{Air} = volume of fresh air entered in intake manifold.

As the load increases, diesel engines start generating more smoke because of reduction in oxygen availability in combustion zone. Zelenka et al. have shown that as high EGR can be used at lower engine loads whereas at high loading condition, low EGR must be used [7]. The use of 10–25% EGR results in significant reduction in NO_x with a smaller rise in PM emissions without affecting the performance of engine [8–10].

Though EGR effectively reduces NO_x emission, rise in PM emissions leads to increase wear of vital engine parts such as cylinder liner, piston rings, bearings, valve train etc. The wear debris generated by wear of various engine parts contaminates the lubricating oil. Therefore, engines operated with EGR are normally exhibit higher level of lubricating oil contaminations and faster degradation of lubricating oil [10].

The objective of current study is to compare the performance of a constant speed diesel engine using EGR with respect to normal operating engine. The effect of EGR on lubricating oil and wear was studied by engine test for 96 h under each condition.

In EGR operated engines, vital engine parts wear faster due to chemical reactions and abrasive action on the surface by increased number of soot particles, and squeezing out of anti-wear film. As a result, lubricating oil is exposed to higher levels of contaminants, which affects the performance and life of lubricating oil and damage the surfaces of various engine parts to a greater extent [11]. Rounds proposed that wear occurs when the decomposition products of the anti-wear additives get preferentially adsorbed onto soot allowing metal-to-metal contact [12]. The diesel soot particles are agglomerates of small, spherical particles of diameter of approximate 0.02 μm and size ranging from 0.5 μm and bigger [13]. Thickness of boundary layer lubricating oil film is characterized as $\geqslant 0.025$ μm, which is significantly less than diameter of soot particles [14]. Low speed and high load engine operations, typically during start up and shutdown, may face insufficient lubrication at boundary layer lubrication zones (i.e. at TDC and BDC positions) of the cylinder liner. Soot particles at times have diameters larger than lubricating oil film thickness. These soot particles start acting as abrasives particles, leading to higher wear of surface materials. From a common oil sump, these abrasive particles circulate throughout the engine and continue the chain reaction of wear [15].

2. Experimental setup and methodology

The engine experiments were conducted in two phases. In the first phase, engine was run under normal operating conditions without EGR (baseline) and in the second phase, the engine was run with a 25% EGR rate. The soot deposition in both phases of experiment was qualitatively compared by taking pictures of in-cylinder engine parts. For comparing the engine wear of both the phases of engine experiments, samples of lubricating oil were collected after every 24 h of engine run and were analyzed for heavy metals and soot content using atomic absorption spectrophotometer (Varian AAS spectra AA 220FS) and total organic carbon (TOC) analyzer (Shimadzu, TOC-V CPN), respectively.

A constant speed, two cylinder, four stroke, air cooled, direct injection, diesel engine (Indec PH2) of 9.7 kW rating coupled with an AC alternator was chosen for this experimental study. The specifications of this engine are given in Table 1.

New set of cylinder liners, piston rings and pistons were installed for each phase of engine experiment. Fresh lubricating oil was filled in oil sump before each set of experiment. There was no further addition of make-up lubricating oil during each phase. After completing each phase, engine was dismantled and cleaned thoroughly by draining out the lubricating oil from the sump.

Experimental EGR setup was fabricated (Fig. 1). The short route EGR systems are more effective than long route system in reduction of NO_x and fuel economy, hence the exhaust gases were recirculated through shortest possible path [16].

An air box is provided to dampen the fluctuations of the recirculating exhaust gas. To measure the volumetric flow rate of recirculating exhaust gas, an orifice plate with a U-tube manometer was installed. To measure vol-

Table 1
Technical specification of the test engines

Manufacturer, Model	Indec PH2, CI Engine
Bore diameter	87.3 mm
Stroke length	110 mm
Power per cylinder	4.85 kW@1500 rpm
Compression ratio	16.5:1
Displacement	1318 cc
Fuel injection pressure	210 kg/cm^2