DIESEL EXHAUST PARTICULATES CHARACTERIZATION FOR HEAVY METALS

K V L Bharathi¹, Dipankar Dwivedi¹, Avinash Kumar Agarwal², Mukesh Sharma¹
Environmental Engineering Program¹ and Department of Mechanical Engineering²
Indian Institute of Technology Kanpur, India
Corresponding Author’s email: akag@iitk.ac.in

Abstract
This study was set out to characterize particulate emissions from transportation diesel engine in terms of heavy metals. The exhaust particulates from Mahindra DI engine were collected and analyzed at four different engine operating conditions namely idling, 40%, 70% and full load. It was found that as the load increases from idling to full load, the heavy metal content in particulates gradually decreases. Heavy metal content in the particulate matter was found maximum at idling. This was possibly due to inadequate combustion or low temperature combustion of diesel fuel and lubricating oil during idling. The Heavy metal content in particulates was evaluated along with that of metal content in diesel. An effort has been made to correlate the emission pattern of heavy metals in particulate matter with that of diesel fuel.

Introduction
Diesel engine exhaust is a complex mixture containing several organic and inorganic gaseous species and particulates, formed during combustion process. Diesel engines emit gaseous pollutants and carbonaceous particulate matter, typically described as diesel particulate matter (DPM). The gaseous pollutants contain nitrogen-oxides, carbon-dioxide, carbon-monoxide and many toxic substances including aldehydes. Oxides of nitrogen are major ozone precursors among the combustion products in the gaseous phase. The particulate matter consists of an elemental carbon core with several organic compounds, sulfates, nitrogen-oxides, heavy metals, trace elements and irritants (such as acrolein, ammonia, acids, fuel vapors, unburnt lubricating oils, moisture) absorbed to its surface. The particle size distribution and chemical composition of diesel exhaust emissions can vary greatly depending on the engine type, engine speed and load, fuel composition, lubricating oil type and emission control technology (California Environmental Protection Agency, 1998). According to a study conducted by EPA, approximately 90% of diesel particles have diameter less than 1 micron and at least 94% are less than 2.5 microns (Health Effects institute, 1995). EPA also concluded that it is not yet clear if the risk of diesel emissions has decreased over time with improvements in engine technologies (EPA, 2000). Since it is clearly established that diesel exhaust is harmful for public health and the degree of toxicity of the exhaust is function of particle size and its chemical composition, which itself is varying due to changes in technology, there is a need to study both emission of particulate matter and its chemical composition from diesel exhaust. Exposure to heavy metals causes adverse health effects (Chow et al. 1994) including toxicity.

Hare (1977) found that the metallic elements emitted from the four-stroke heavy-duty engine include silicon, copper, calcium, zinc and phosphorous, whereas in two stroke engines, the metallic elements in emissions are lead, manganese, chromium, zinc and calcium. Calcium, phosphorous and zinc are normally present in engine lubricating oil as additives. Lowenthal et. al. (1994) reported that abundant metals in exhaust were zinc, iron, calcium, phosphorous, barium and lanthanum. The total emission of metals was less than 0.3 percent of total diesel particulate matter mass, with an emissions rate of 1.65 mg/ km.
**Experimental Setup**

Mahindra DI 2500 diesel engine was used for this study. The engine is a Four-Cylinder, Four-Stroke engine with direct-injection. This engine was installed with a Shenck-Avery make eddy-current dynamometer. To characterize emissions, engine was operated at idling, 40%, 70%, 100% (Full load) load conditions. In view of the objectives of the research concerning characterization of the particulates, heavy metal content in particulates from Mahindra DI 2500 engine exhaust are to be analyzed. Diesel Particulate samples were collected isokinetically for analyzing heavy metals. An effort has been made to correlate the metal content in particulates with that of heavy metals in diesel fuel. Heavy metals were analyzed in the samples collected by filtering the exhaust through thimbles (samples collected from the tail pipe of the engine), diesel oil and fresh lubricant oil, in order to identify the presence of following metals; Fe, Mg, Cr, Ni, Pb, Zn, Ca and Ba.

![Dynamometer Setup](image)

**Figure 1: Dynamometer Setup**

Particulate matter emitted from tail pipe was collected using a stack gas kit (Make: Envirotech, Delhi; Model: APM 620). The sampling arrangement consisted of nozzle, thimble holder, rotameter and a vacuum pump. The installed thimble was desiccated for 12 hours prior to sampling and it was weighed initially.

AAS has been one of the most commonly used techniques for analyzing heavy metals in particulates, diesel and lubricant oil.

**Results and discussion**

the objectives of this study was to determine metal contents in DPM and diesel oil; Fe, Mg, Cr, Ni, Pb, Zn, Ca, Ba and Cd were measured in DPM and diesel oil under various engine load conditions (Tables 1). The experimental study showed that concentrations of Fe, Mg, Ca (crust elements) were much higher than those of the Cr, Ni, Pb, Zn, Ba and Cd (anthropogenic elements). Figures 2a and 2b present the variation of concentration of crust and anthropogenic elements in DPM with respect to engine load. The metal concentrations of this study have been compared with the results of Wang et al. (2003).
Table 1: Metal Concentrations in Particulates of Diesel Engine Exhaust and Diesel Fuel

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Metal</th>
<th>Metal Concentration (µg/m³)</th>
<th>Engine Load</th>
<th>Diesel Fuel (µg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Idle</td>
<td>40%</td>
</tr>
<tr>
<td>1</td>
<td>Fe</td>
<td>258</td>
<td>221.2</td>
<td>195.6</td>
</tr>
<tr>
<td>2</td>
<td>Mg</td>
<td>125</td>
<td>112.8</td>
<td>95.4</td>
</tr>
<tr>
<td>3</td>
<td>Cr</td>
<td>59.2</td>
<td>46.3</td>
<td>35.2</td>
</tr>
<tr>
<td>4</td>
<td>Ni</td>
<td>42.1</td>
<td>36.0</td>
<td>32.2</td>
</tr>
<tr>
<td>5</td>
<td>Pb</td>
<td>35.2</td>
<td>28.1</td>
<td>24.6</td>
</tr>
<tr>
<td>6</td>
<td>Zn</td>
<td>85.6</td>
<td>76.3</td>
<td>72.5</td>
</tr>
<tr>
<td>7</td>
<td>Ca</td>
<td>936</td>
<td>845</td>
<td>823</td>
</tr>
<tr>
<td>8</td>
<td>Ba</td>
<td>16.1</td>
<td>14.9</td>
<td>13.5</td>
</tr>
<tr>
<td>9</td>
<td>Cd</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

Figure 2a: Variation of Concentration of Fe, Mg, and Ca (crust elements) With Engine Load

Figure 2b: Variation of Concentration of Cr, Ni, Pb, Zn, Ba (anthropogenic elements) with Engine Load

It is evident from Figures 2a and 2b that generally the metal levels in DPM decrease with increase in load. The efficiency of diesel engine improves with load typically up to 90 percent of load. In other words, diesel input per unit of power derived decrease and that is reflected in reduced emission of metals with load. These figures support the fact that metal content in diesel can possibly play an important role in the emission of metals in the DPM.
An attempt has been made to examine the influence of metal content in diesel on metal content in DPM (Figure 3). The correlation coefficient between metal contents of diesel and in DPM was found to be 0.73. Although it is not possible to estimate the emission of metals per unit consumption of diesel (as specific diesel consumption was not measured under various load conditions), the high correlation and Figure 3 suggest that concentrations of metals in DPM are mostly dependent on metals concentration in diesel.

Conclusions
The emission of the metals in vehicle exhausts could be mostly explained by the consumption of metal contents in diesel fuel. Although the emissions of anthropogenic elements from diesel vehicle exhaust were much less than that of crust elements, the contribution of the former to the ambient environment could be much more significant than the later. Finally, in this study we found that the increase of the engine loads would lead to decrease in metal contents contained in particulate matters. But it should be noted that the concentrations of metal contents contained in the diesel fuel used in this study could be very different from those used in other countries. The results obtained from this study could be valid only for the particular fuel studies and hence should used with caution in other researches.

References


