Can copper leaching from the fuel line of a HPCR diesel engine affect the combustion characteristics and particulate emissions?

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Introduction: The presence of metallic particles in the fuel can be linked to the interaction between fuel and fuel injection equipment. Corrosion behaviour of aluminium, copper, and stainless steel in diesel and their impact on fuel properties has been quantified [1]. The catalytic activity of metallic-based fuel additives has been investigated widely; there is a consensus in the literature on the positive effect of metallic additives on combustion enhancement and emission reduction [2]. Despite this the effect of fuel contamination from the leached metals on emissions and combustion characteristics has not been reported. The leaching of metals from a helicoidally shaped copper duct installed along the low-pressure fuel line in a diesel engine was investigated and the results presented here.

Methodology: Coils, powered at 13.5 V and surrounding the copper pipe, heat the metal and promote the leaching. Copper concentration in the diesel fuel was measured using Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES). A fully instrumented Euro-V HPCR DI 2.2 litre diesel engine was run at constant engine speeds of 1500 and 2000 rpm, and at constant loads of 3 and 5 bar BMEP. A pilot plus main injection strategy was used. The fuel tank was filled with diesel fuel with a copper content less than 0.01 mg kg^{-1}. Experiments were carried out over two days, with fuel samples collected at end of each day of testing. The experimentally acquired in-cylinder pressure data was used to investigate combustion characteristics. An AVL Smoke Meter was used to measure the soot concentration emitted by the diesel engine.

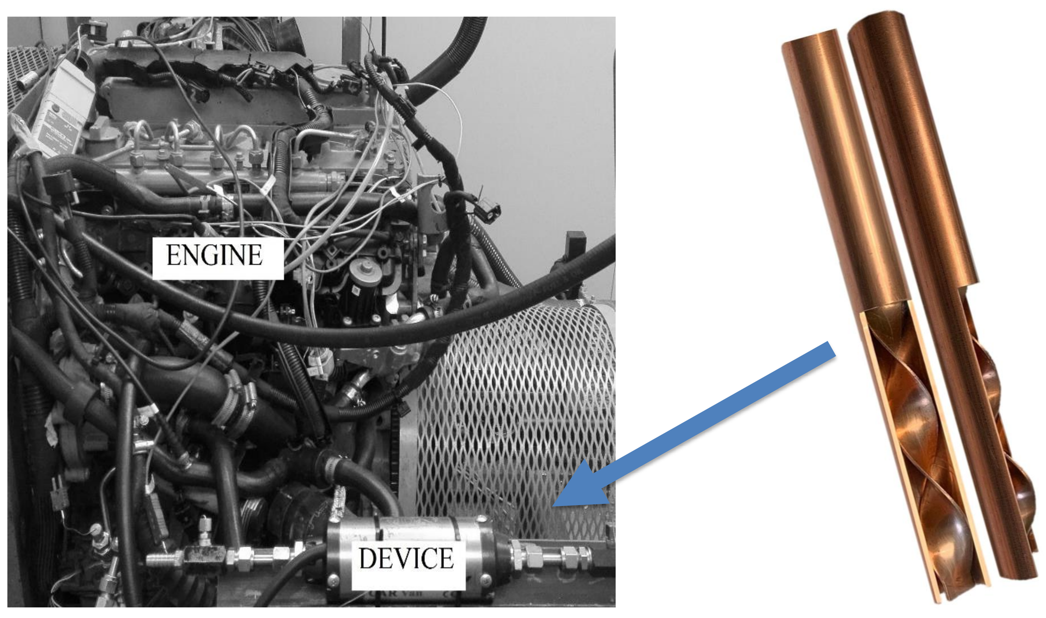


Figure 1. Device and helicoidally shaped copper duct installed prior to high pressure fuel pump

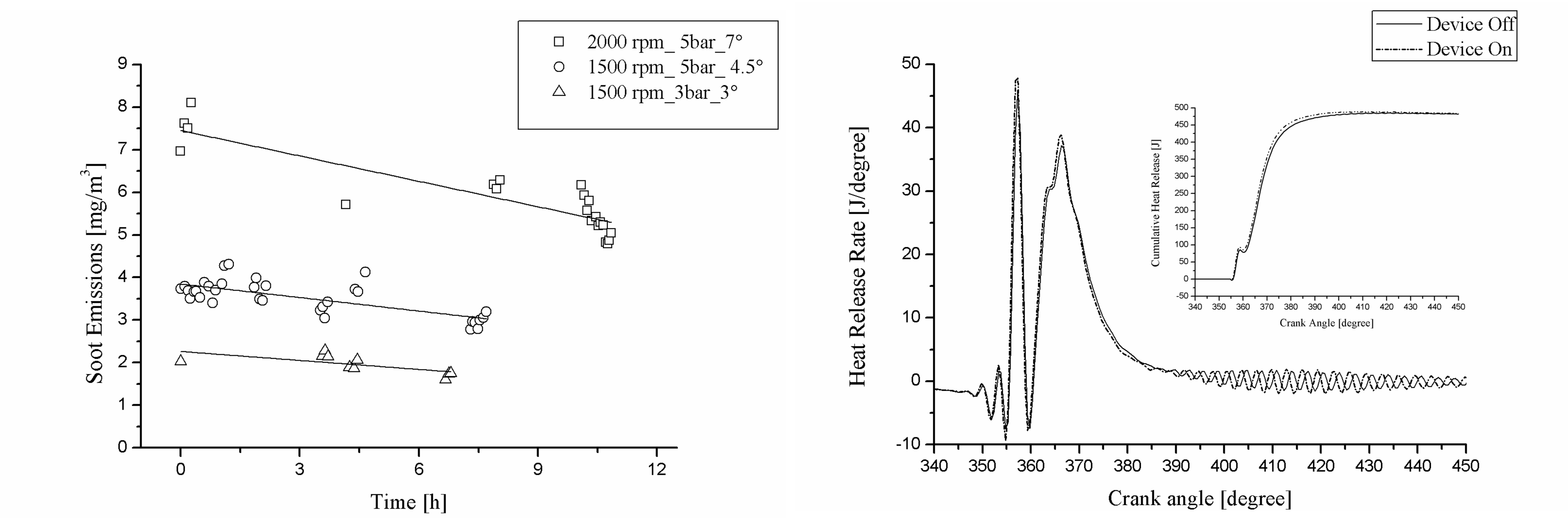


Figure 2. Soot concentration measurements at different operating conditions (left). An example of cumulative and heat release rate showing no change in the ignition delay (right)

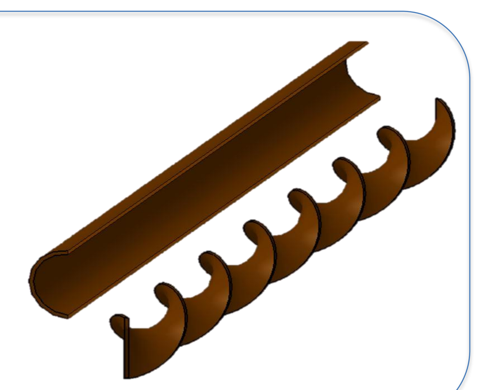
Results: 33 kg h^{-1} of diesel flowed through the helicoidally shaped copper duct, while only 3-4 kg h^{-1} were injected into the four cylinders; the remainder is recirculated into the fuel tank. ICP-OES analysis showed an average rate of copper release in the diesel of 0.012 mg kg^{-1} h^{-1}. At the end of the last day of testing the total copper concentration accumulated in the fuel tank was 0.19 mg kg^{-1}. We have no information on the size/shape of copper in the dispersion and whether this dispersion is stable over time.

Diesel sample	Copper content
A (baseline)	0.01 mg kg^{-1}
B	0.12 mg kg^{-1}
C	0.19 mg kg^{-1}

$$\text{Leaching rate} = \frac{87.6 * m_{copper}}{\rho * A_{tot} * 25.4 * t} * 10^3 = 0.0418\ mpy$$

Copper leaching rate consistent with that indicated in the technical literature, between 0.042 mpy and 0.053 mpy [3].

A_{tot} = interface area between fuel and device



Soot emissions decrease as copper concentration increases. As shown in Figure 2, a maximum reduction of 27% was measured across the two days for the 2000 rpm 5 bar case, while a 14.6% reduction was measured for the 1500 rpm 5 bar case. A reduction of 13% was measured at the lower load. Metallic additives can act as catalysts for the combustion process and for promoting oxidation of carbon nanoparticles formed during combustion. Analysis of the heat release showed that fuel starts to combust shortly after the main injection, but there is no change in the ignition delay, see Figure 2. This suggests that physical/chemical delay and fuel/air mixture preparation before ignition are not the reasons of soot reduction. Our hypothesis is that the catalytic effect of the leached copper promotes soot oxidation. A slightly shorter CA50 was also noticed when copper contaminated fuel is combusted. The magnitude of the soot reduction reported here is consistent with the results obtained using two other DI diesel engines.

Conclusions: The helicoidally shaped copper duct results in fuel contamination. A maximum soot reduction of 27% was measured as copper content in the fuel increases from 0.01 to 19mg kg^{-1}. The greater soot reduction was noticed at the high load/speed case.
Our hypothesis is that soot reduction is promoted by the leaching of metals into the fuel; the copper acts as a catalyst for soot oxidation.

Future work: A full investigation covering a wider range of operating conditions will be performed. The relationship between duct temperature and leaching rates of copper into the fuel will be explored. If copper is used in conjunction with particulate filters, secondary emission may form [4]; therefore further investigation is needed to understand the impact of metals on the secondary emissions when a particulate filter is used, and whether a minimum permissible dose of copper can be defined.

References:

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