

Crankcase Sampling of PM from a Fired and Motored Compression Ignition Engine

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Benjamin T. Johnson, Graham K. Hargrave and Benjamin Reid
Loughborough University

Vivian J. Page
Perkins Engines Co Ltd

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ABSTRACT

Crankcase emissions are a complex mixture of combustion products and aerosol generated from lubrication oil. The crankcase emissions contribute substantially to the total particulate matter (PM) emitted from an engine. Environment legislation demands that either the combustion and crankcase emissions are combined to give a total measurement, or the crankcase gases are re-circulated back into the engine. There is a lack of understanding regarding the physical processes that generate crankcase aerosols, with a paucity of information on the size/mass concentrations of particles present in the crankcase. In this study the particulate matter crankcase emissions were measured from a fired and motored 4 cylinder compression ignition engine at a range of speeds and crankcase locations. A sequence of sampling equipment was used to characterise the emissions in the size range 5 nm - 19 µm; Cambustion DMS500 fast particulate spectrometer, TSI Scanning Mobility Particle Sizer (SMPS), TSI™ Condensation Particle Counter (CPC) and, TSI™ Aerodynamic Particle Sizer (APS). The combination of the two test engines and range of sampling equipment provided new information on the generation and behavior of aerodynamic particulate matter within an engine crankcase. Data is presented for the effect of controlled parameter changes on number distributions over the measured particle size range. A complex lognormal bimodal size distribution of sub micron accumulation mode particles was present in the crankcase of both engines at a low idle speed of 900rpm. At 1400rpm this complex distribution was not present. Increasing the engine load, on the fired engine, initially reduced the particle number concentration with a final significant increase in particle number concentration at 75%

load. At 900 rpm 50% load there was a single strong peak at 32nm in the rocker cover however sampling from the push rod gallery and sump showed a strongly bimodal distribution with peaks at 32nm and 133nm. All other sampling data, from the fired engine, was consistent at each sampling location. The SMPS results, 15-665nm, on the motored engine showed location dependency, with the highest number concentration of particles present in the push rod gallery.

INTRODUCTION

Since 2007 the US Environmental Protection Agency (EPA), and more recently European legislation, has ruled if closed crankcase ventilation (CCV) is not used crankcase emissions must be added to tailpipe emissions giving a total emissions measurement. Crankcase emissions are a complex mixture of combustion products, including water vapor, un-burnt fuel and most significantly particulate matter. Crankcase particulate matter can contribute over 20% of the total particulate matter emissions from an engine, whereas crankcase emissions of HC, NO_x and CO contribute only 3.7%, 0.1%, 1.3% respectively to the total engine emissions [Schmeichel et al 2007] [Clark & Tatli 2006]. Figure 1 illustrates the magnitude of the problem. Whilst efforts have been concentrated on tail pipe particulate matter, the contribution of the crankcase particulate matter has become more significant overall. Clark et al [2006] found that the engine lubrication oil contributed to approximately 50% of the particulate matter emissions from the crankcase, the other 50% was associated with combustion emissions and wear of components. Particulate matter can be characterized by its particle size distribution, studies have found aerosols containing particles ranging from 50 nm to 10µm in diameter

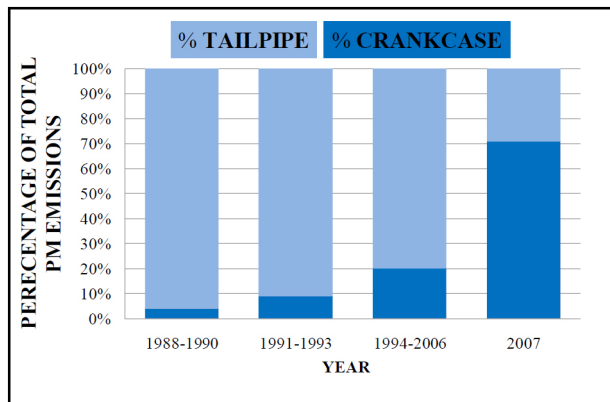


Figure 1. Crankcase emissions levels in diesel engines
[Donaldson 2008]

Large particles, 10-20 μm , can be removed from the crankcase emissions using impaction separators in which the blow-by is forced through a rapid change in geometry; suspended oil particles cannot follow the flow path and are impacted onto a surface then drained away. With comprehensive knowledge of the aerodynamic particle loading an impaction separator device was developed at Loughborough university, [Long et al 2009], to control particles down to 1 μm . Removing sub-micron particles requires more restrictive geometry, this increases the back pressure on the crankcase and impaction becomes substantially more complicated to control. To achieve the desired filtration efficiency, filters become very complex, involving dynamic and consumable components.

The contribution of both combustion products and lubrication oil to engine emissions is of great concern however, there is little research or literature explaining the generation and transport of particulate matter through an engine crankcase. Research has focused on reducing the particulate matter at the crankcase breather with few attempts to understand any sources of aerosol generation and oil atomization within the crankcase. This body of research provides a thorough investigation of the aerodynamic particles 5nm-19 μm present at a range of locations around the crankcase in both fired and motored Tier 2 compression ignition (CI) engines. The motored and fired engines were setup in parallel enabling the contribution of lubricant oil to crankcase particulate matter emissions to be identified. Running with stable conditions the effect of changes to engine speed, load and oil temperature on the particulate matter number distribution is presented.

EXPERIMENTAL TESTING

A fundamental study of particulate matter emitted from the crankcase on both a fired and motored Tier 2 diesel engine was conducted at Loughborough University. The engine block and internal components within the crankcase were identical for both engines, full engine specifications and oil types are shown in the [Appendix Tables 2, 3, 4, 5](#). 5w30 oil was used on the motored engine and 10w40 on the fired engine, at 100°C their kinematic viscosities differ by 2.87 mm^2/s . Three types of sampling equipment were used to characterize the crankcase particulate matter emissions, these were, the Cambustion DMS500 MkII fast particulate spectrometer measuring particles 5nm - 1 μm , the TSI SMPS and CPC measuring particles 15nm - 661nm and the APS measuring particles 0.542 μm -19.81 μm .

FIRED ENGINE

The fired engine particulate matter was sampled using the Cambustion DMS500 MkII fast particulate spectrometer at three crankcase locations as shown in [Figure 2](#); oil filler cap in the rocker cover, push rod gallery core plug and dipstick mounting hole in the sump. A sample was extracted from the crankcase into a 50mm length of Φ 8mm pipe. A k-type thermocouple was used to measure the sample temperature via a stainless steel t-junction, a second 50mm section of Φ 8mm copper pipe connected the t-junction to the Cambustion DMS500 heated line. Within the heated line the sample passed initially through a heated cyclone before the reaching the DMS500 fast particulate spectrometer. The engine exhaust was sampled separately as shown in [Figure 3](#), a 250mm length of Φ 6mm stainless steel pipe was positioned in the centre of the exhaust flow.

The DMS500 has an integrated two-stage dilution system, primary dilution occurs at the sampling point in the heated line where compressed air is passed through a HEPA filter and then used to dilute the sample. Secondary high ratio dilution is applied using a rotating disc diluter, [Figure 15](#) shows a schematic of the full dilution system. Both primary and secondary dilution was used on the DMS500 for fired engine crankcase particulate matter emission measurement. A sample of 8 litres/min was extracted from the specific sampling point and diluted to an appropriate level, the DMS500 was calibrated to correct for dilution ratio.

The fired engine was directly coupled to an eddy current dynamometer, within an engine test cell. Test were conducted at speeds of 900rpm and 1400rpm and loads of 0,25,50 and 75%. K-type thermocouple measurements were taken at the following locations: sump oil, post compressor air temperature, oil film above the push rod gallery, gas temperature at the top and bottom of the push rod gallery, the three sampling points and coolant temperature in the thermostat housing. The oil rail pressure was also monitored.

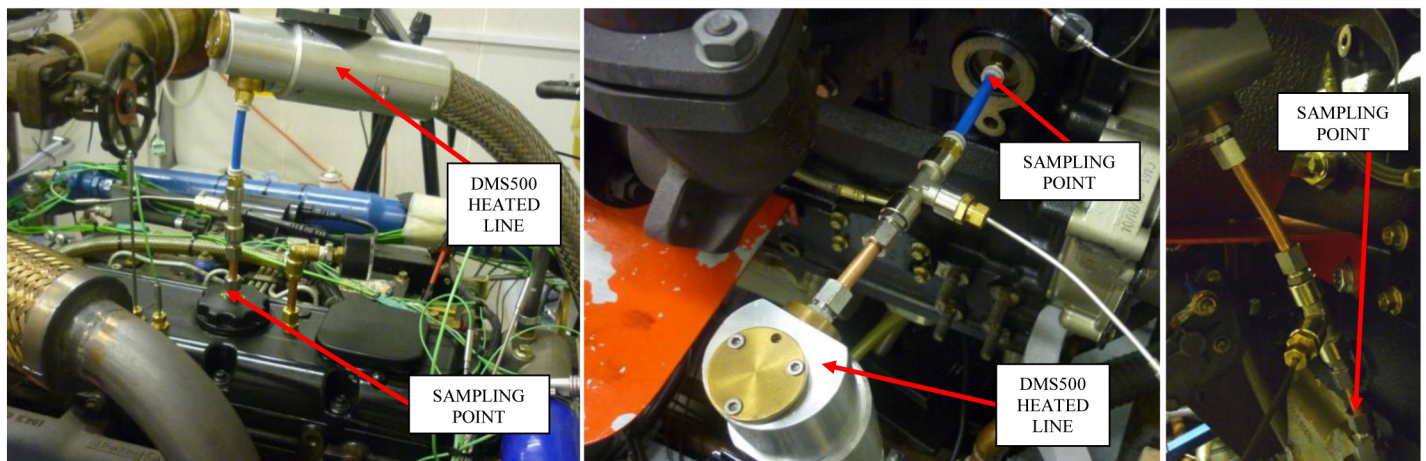


Figure 2. Fired engine DMS500 sampling points (a) rocker cover (b) push rod gallery core plug (c) sump dipstick mount

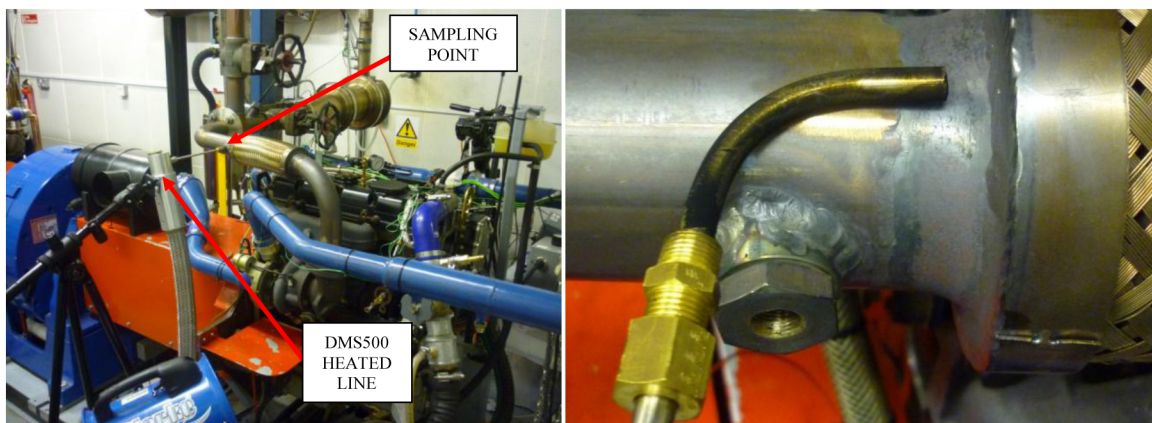


Figure 3. Fired engine (a) dynamometer and cell installation (b) exhaust sampling point

A dynamometer control was used to fix the engine speed and load, the engine temperatures were stable before completing all steady state sampling tests. Additionally an AVL244 blow-by meter with two damping chambers was used to measure the blow-by flow rate.

MOTORED ENGINE

The motored engine sampling analysis was conducted using the TSI™ SMPS, CPC and the APS. The APS sample was diluted using a closed system aerosol diluter in increments of 20:1 or 100:1. A small sample of the aerosol is diluted with filtered air from the original sample, this maintains the sample elemental composition, temperature and relative humidity. The filtered air is reunited with the sample flow through a multi-hole mixing cone. Pressure gauges are used to monitor the aerosol path and total path flow rates. A valve on the filter side of the diluter can be used to adjust the pressure drop to match calibrated values. The engine was driven, by a 30 kW electric motor and controller, to a maximum speed of 900 rpm. The inducted cylinder volume was vented via the fuel injector and glow plug holes, [Figure](#)

4. A temperature controlled steady state crankcase flow was introduced below the piston skirt, the crankcase flow air temperature was kept at 110 °C. Sampling tests were conducted at crankcase flow rates of 40, 60, 80, 100, 150, 200 litres/min and speeds of 360, 600 and 900rpm. The engine coolant circuit was used to stabilize the engine temperature, and an external circuit was used to heat the engine oil, once at the specified temperature the oil was lifted into the engine sump and circulated around the engine.

Again samples were taken from three locations around the crankcase of the engine: dipstick mounting hole, 100 mm down the push rod gallery and oil filler cap. The crankcase was fully vented via the specific sampling point, a 300mm length of Φ 8mm copper pipe was connected to the sampling point. The flow was then channeled into a 25mm rubber pipe before entering a Φ 40mm stainless steel sampling pipe, samples were extracted from two 90° tappings in the centre of the sampling pipe connected to the APS (Φ 20mm pipe) and SMPS (Φ 10mm pipe). The remaining flow was vented to the extraction system.

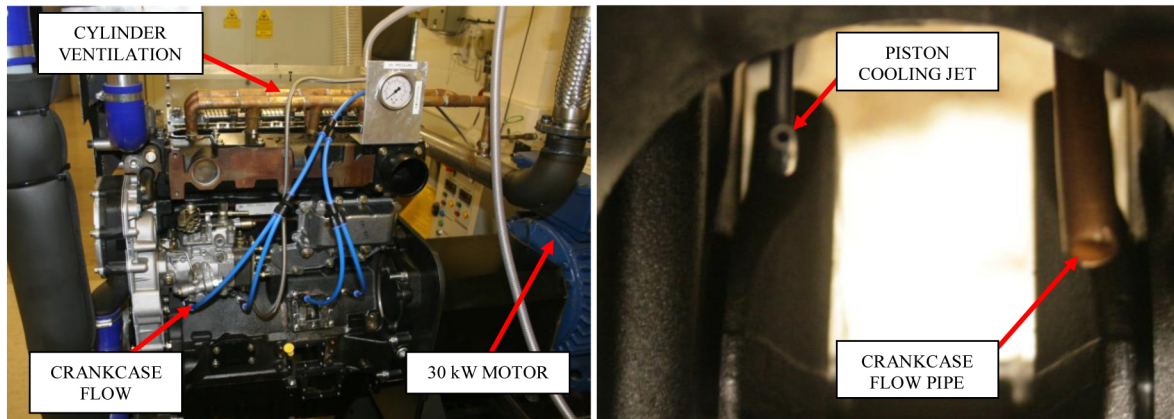


Figure 4. (a) Motored engine (b) copper injection pipe introducing crankcase flow

RESULTS

REPEATABILITY

To assess the repeatability of the sampling equipment three sets of data were collected at each test point. Figure 5 shows the repeatability of the DMS500 results on the fired engine at a range of engine loads when sampling at a fast idle speed of 900rpm from the push rod gallery. The variation in peak number concentration from a mean value was approximately 15% for all engines loads, with a maximum of 27% at 75% load. Although the variation in number concentration is significant, the peak particle number concentration and trend across the measured particle size range is consistent. The data processing software was set to correct for dilution ratio, adjusting the dilution ratio was found to have no marked effect on the sampling results from the DMS500. Once the engine temperatures were stable sampling was conducted for 20 minutes. A typical contour plot is presented in Figure 6 and shows there is little fluctuation in the sampling equipment for stable engine conditions. The initial results showed good repeatability in both the size distribution and the contour plots over the test duration. To increase the range of test conditions the test duration was dropped to 15 minutes, then with continued repeatability 10 minutes, however three repeats were still completed for each test point to enable better assessment of the data. The SMPS and APS equipment used on the motored engine showed similar repeatability to that of the DMS500 for repeat tests at stable engine conditions.

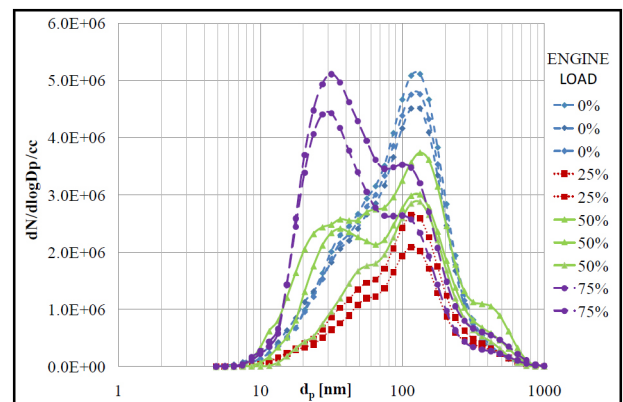


Figure 5. DMS500 size distribution of crankcase particulate matter for varying engine load at 900 rpm sampling from the push rod gallery on the fired engine

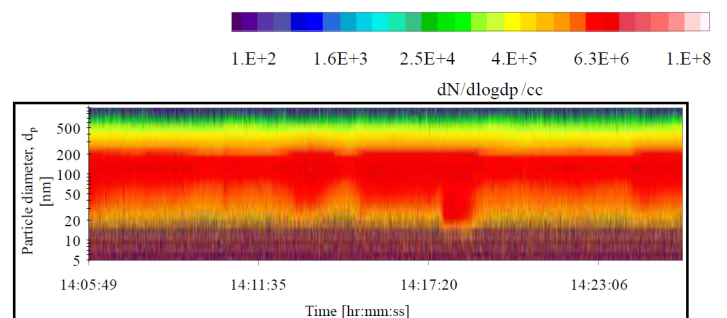


Figure 6. DMS500 contour plot at 900rpm 0% load sampling from the push rod gallery on the fired engine

LOAD VARIATION

Figure 5 highlights the significant effect of varying the engine load on the size distribution for the fired engine crankcase emissions when sampling from the push rod gallery, the push gallery gas temperatures at the tested engine loads are shown in Table 1. Initially, with no load, and